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FINAL BEACH DYNAMICS INVESTIGATION REPORT ATLANTIC FLEET WEAPONS TRAINING AREA, FORMER NAVAL AMMUNITION SUPPORT DETACHMENT AND FORMER VIEQUES NAVAL TRAINING RANGE VIEQUES PUERTO RICO

11/01/2018

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Atlantic
Norfolk, Virginia

Final

Beach Dynamics Investigation Report

Atlantic Fleet Weapons Training Area – Vieques
Former Naval Ammunition Support Detachment and
Former Vieques Naval Training Range
Vieques, Puerto Rico

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November 2018

Prepared for NAVFAC Atlantic
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Executive Summary

This Beach Dynamics Investigation (BDI) report presents the findings, conclusions, and recommendations of the BDI performed at 11 beaches. Ten beaches are located at the former Vieques Naval Training Range (VNTR) and one at the former Naval Ammunition Support Detachment (NASD) in Vieques, Puerto Rico (**Figures ES-1 through ES-3**). Beaches selected are representative of the broad range of characteristics found across Vieques.

The primary objective of the BDI was to develop an understanding of beach and nearshore changes, and their relationship to the burial and mobility of munitions and explosives of concern (MEC) for the range of metocean (meteorological and oceanographic) conditions experienced during the BDI.

If deemed beneficial in the future, the BDI data and information can be utilized to calibrate and validate numerical models for the development of long-term predictions of beach changes and the burial and mobility of MEC in a wide range of metocean conditions.

The majority of BDI activities were conducted from October 2014 through February 2016, with additional beach surveys in October and November 2017 to evaluate the impact of the August 2017 Hurricane Irma and the September 2017 Hurricane Maria, as well as an additional surrogate tracking event in February 2018.

The BDI included several metocean measurements, surveys, sampling, and observations, including continuous wave measurements at three locations around the island of Vieques, collection of concurrent water level from the National Oceanic and Atmospheric Administration (NOAA) stations, and continuous rain gauge measurement at Camp Garcia. Metocean field observations were performed during the monthly beach surveys and quarterly beach sediment sampling. Additionally, third-party metocean data were collected monthly to characterize local and regional conditions during the BDI.

To augment the current understanding of the impact of the dynamic behavior of the beaches and metocean conditions in Vieques on the burial and mobility of MEC, 61 inert surrogates representing 6 types of MEC were deployed offshore of nine beaches located in the Live Impact Area, the Eastern Maneuver Area (north side), and the Surface Impact Area (north and south sides), and their locations were surveyed (tracked) approximately monthly and generally concurrently with the beach surveys.

Using the aforementioned metocean data assessment, characteristics were defined for each of the 11 beaches to assess beach changes, and the burial and mobility of MEC: dynamics, beach profiles, area of beach change, depth of closure, landward limit of beach change, shoreline position, rainfall and surface water runoff, and MEC burial and mobility. The conclusions are as follows:

- **Dynamics** - Dynamic beaches, such as Beaches 1, 2, 12, 14, and 24, are exposed (oriented) toward the typical wave climate and/or have no or little protection from headlands, bays, and reefs. Stable beaches, such as 3, 4, 5, 19, 22 and Solid Waste Management Unit (SWMU) 4, are not exposed to the typical wave climate and/or are protected by headlands, bays, and reefs.
- **Beach Profiles** - At dynamic beaches, beach profiles landward or seaward of the shoreline exhibited average maximum elevation changes greater than 0.8 meter (m), while at stable beaches these changes were less than 0.8 m. An exception was Beach 22 (west) where waves, bathymetry and a headland interacted at transect 7 to generate a profile elevation change of 1.48 m. This exceeded what was typical elsewhere at this beach and biased the average maximum elevation change to 0.96 m.
- **Areas of Beach Change** - The BDI showed that the width of the area of beach change was greater than 50 m at dynamic beaches, and less than 50 m at stable beaches.
- **Depth of Closure** - At dynamic beaches, depths of closure are greater than -2 m PRVD02 (Puerto Rico Vertical Datum 2002), while at stable beaches these are less than -2 m PRVD02.

NOTE: THIS SUMMARY IS PRESENTED IN ENGLISH AND SPANISH FOR THE CONVENIENCE OF THE READER. EVERY EFFORT HAS BEEN MADE FOR THE TRANSLATIONS TO BE AS ACCURATE AS REASONABLY POSSIBLE. HOWEVER, READERS SHOULD BE AWARE THAT THE ENGLISH VERSION OF THE TEXT IS THE OFFICIAL VERSION.

- **Landward Limit of Beach Change** - At all beaches, the landward limit of beach change was generally parallel to the shoreline and, at some locations, it bordered the vegetation line. Wave heights in the nearshore at dynamic beaches were greater than 0.5 m, while at stable beaches wave heights were less than 0.5 m to near zero. At the dynamic beaches where the waves were higher, the landward limit of beach change reached average elevations greater than 1 m PRVD02, while at stable beaches the average elevation changes were less than 1 m PRVD02.
- **Shoreline Position** - At dynamic beaches, the ranges of shoreline positions were greater than 5 m, while at stable beaches these were less than 5 m (except at Beaches 3, 5, and 22). Hurricane Maria hit Vieques on September 20, 2017, which generated high waves and storm surge that were particularly damaging to Vieques' south coast.
- **Rainfall and Surface Water Runoff** - Rainfall, was lower than typical in 2015 and typical thereafter, with extreme rainfall in November 2016 and during the passage of Hurricanes Irma and Maria in September 2017. It was concluded that beach changes during the BDI were typical, and attributed solely to waves, water levels, and currents, with localized beach changes when a series of extreme rainfall events occur in a short time.
- **MEC Burial and Mobility -** In general, MEC will remain on top of hard bottoms, remain on top or partially self-bury in seagrass, and partially or self-bury completely in sandy bottoms. In normal wave conditions and sandy bottoms, the tendency of MEC is to self-bury, depending on the water depth. The depth of burial depth decreases as the water depth increases. MEC located in areas of beach change (e.g., landward of the depth of closure) would tend to self-bury deeper (more than one diameter) due to beach-wide bottom changes. Except for extreme wave conditions, MEC located seaward of the depth of closure (and generally even landward of the depth of closure) would not exhibit appreciable mobility and buried MEC will remain buried.

The conceptual-level tools developed for the estimation of depth of burial and potential mobility of MEC from this BDI could be used together with maps of bottom structure and cover to infer where MEC could be present, explain observations from other studies, and plan future investigations, remediation, and/or long-term monitoring.

Resumen Ejecutivo

Este Estudio de Dinámicas de Playas (BDI, por sus siglas en inglés) presenta los hallazgos, conclusiones y recomendaciones del BDI efectuado en 11 playas. Diez de estas playas están localizadas en el Antiguo Campo de Adiestramiento Naval de Vieques (VNTR, por sus siglas en inglés) y una está situada en el Antiguo Destacamento de Apoyo a Municiones Navales (NASD, por sus siglas en inglés) en Vieques, Puerto Rico (**Figuras ES-1 a la ES-3**). Las playas seleccionadas son representativas de la amplia gama de características halladas en Vieques.

El objetivo primario del BDI era desarrollar un mejor entendimiento de los cambios en las playas y condiciones costaneras, así como la relación de estos cambios con el enterramiento y movimiento de las municiones y explosivos de preocupación (MEC, por sus siglas en inglés) dentro de la gama de condiciones metoceánicas (meteorológicas y oceanográficas) experimentadas durante el BDI.

Si se considera beneficio en el futuro, los datos e información del BDI podrían utilizarse para calibrar y validar modelos numéricos para el l desarrollo de predicciones a largo plazo de los cambios en las playas y del enterramiento y movimiento de MEC bajo una amplia gama de condiciones metoceánicas.

La mayoría de las actividades del BDI se llevaron a cabo desde octubre de 2014 hasta febrero de 2016, con inspecciones adicionales de las playas en octubre y noviembre de 2017, a fin de evaluar el impacto del Huracán Irma de agosto 2017 y el Huracán María de septiembre 2017, al igual que un evento adicional de rastreo de municiones sustitutas llevado a cabo en febrero de 2018.

El BDI incluyó varias mediciones, inspecciones, muestreos y observaciones metoceánicas tales como medición continua del oleaje en tres puntos alrededor de Vieques, la recopilación simultánea de niveles de agua de estaciones de la Administración Nacional para el Estudio de los Océanos y la Atmósfera de los EE.UU. (NOAA, por sus siglas en inglés), y mediciones pluviométricas continuas en el Campamento García. Se hicieron observaciones de campo de las condiciones metoceánicas como parte de las inspecciones mensuales de las playas y de los muestreos trimestrales de sedimentos en las playas. Finalmente, datos metoceánicos fueron recopilados mensualmente por consultores externos para caracterizar las condiciones locales y regionales durante el BDI.

Para comprender mejor como impacta la comportamiento dinámico de las playas y de las condiciones metoceánicas el enterramiento y movimiento de los MEC en Vieques, se colocaron 61 sustitutos inertes que representaban 6 tipos de MEC fuera de la costa en nueve playas dentro del Área de Impacto con Bala Viva, Área de Maniobras del Este (lado norte) y el Área de Impacto a la Superficie (lados norte y sur), y sus localizaciones fueron rastreadas aproximadamente cada mes, coincidiendo generalmente con las inspecciones de las playas.

Utilizando la evaluación de los datos metoceánicos indicados anteriormente, se definieron una serie de características para cada una de las once playas para evaluar los cambios en las playas y el enterramiento y movilidad de los MEC, estas características son: dinámica, perfil de la playa, área del cambio en la playa, profundidad del cierre, límite hacia tierra del cambio en las playas, posición de la orilla, lluvia y escorrentía pluvial, y enterramiento y movimiento de los MEC. Se concluyó lo siguiente:

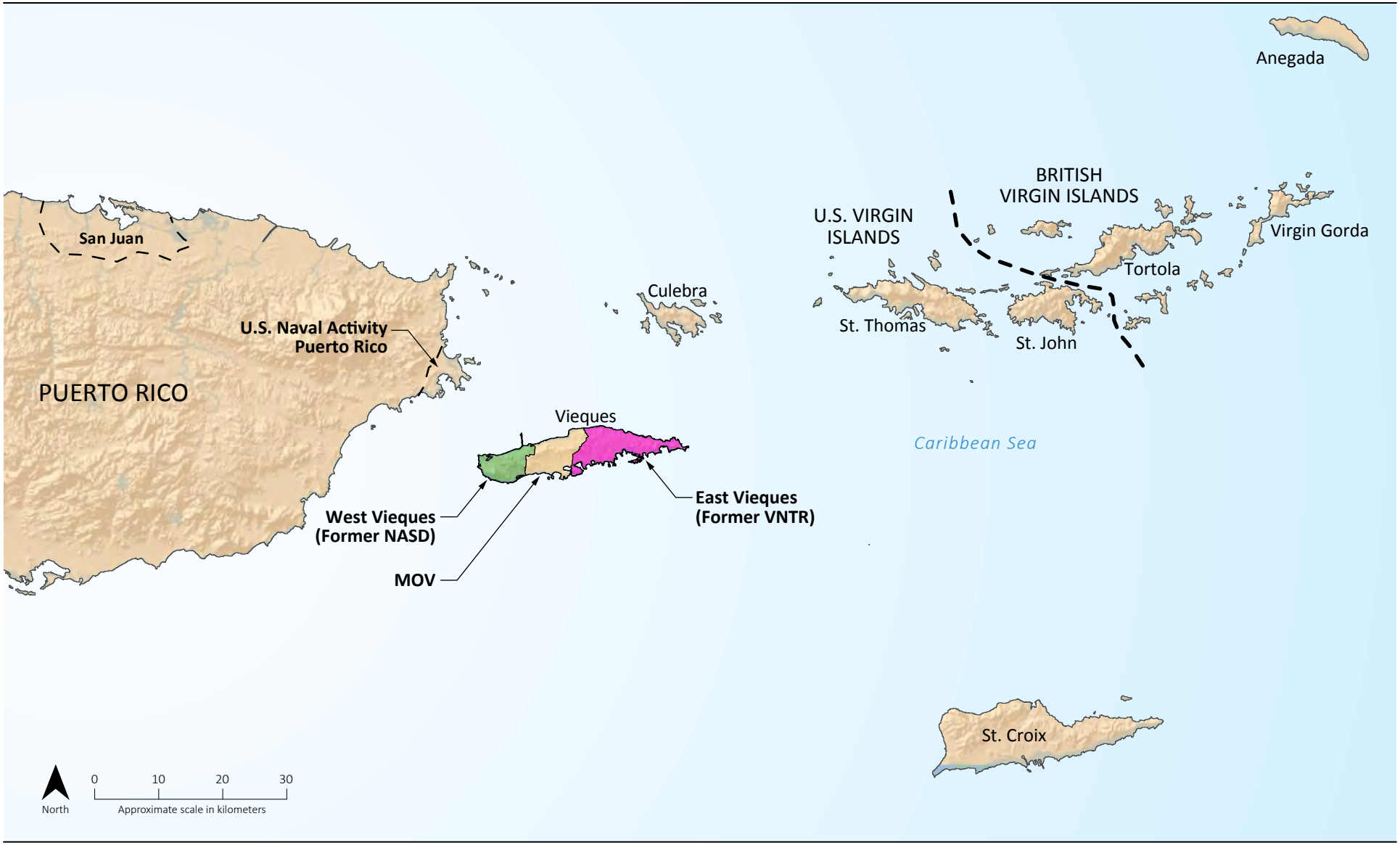
- **Dinámica -** Las playas dinámicas, tales como las Playas 1, 2, 12, 14 y 24, se encuentran expuestas (debido a su orientación) al clima típico de oleaje y/o reciben poca o ninguna protección de cabos, bahías y arrecifes. Las playas estables, tales como la 3, 4, 5, 19, 22 y la Unidad de Manejo de Desperdicios Sólidos (SWMU, por sus siglas en inglés) 4, no sufren exposición al clima típico de oleaje y/o reciben protección de cabos, bahías y arrecifes.
- **Perfiles de las Playas -** El perfil hacia tierra o hacia el mar de las playas dinámicas manifestaron un promedio máximo de cambios en elevación mayor de 0.8 metros (m), mientras que en las playas estables el cambio fue menor de 0.8 m. La playa 22 (su lado oeste) fue la excepción debido a la interacción de las olas, la batimetría y

NOTA: ESTE RESUMEN SE PRESENTA EN INGLÉS Y EN ESPAÑOL PARA LA CONVENIENCIA DEL LECTOR. SE HAN HECHO TODOS LOS ESFUERZOS PARA QUE LA TRADUCCIÓN SEA PRECISA EN LO MÁS RAZONABLEMENTE POSIBLE. SIN EMBARGO, LOS LECTORES DEBEN ESTAR AL TANTO QUE EL TEXTO EN INGLÉS ES LA VERSIÓN OFICIAL.

un cabo en el transecto 7, lo que propició un cambio en el perfil de elevación de 1.48 m. Este valor excedió lo que fue típico en otros sitios de esta playa y sesgó el cambio de elevación en máximo promedio a 0.96 m.

- **Áreas de Cambio en las Playas** - El BDI mostró que la amplitud del área de cambio fue mayor de 50 m en playas dinámicas y menor de 50 m en playas estables.
- **Profundidad del Cierre** - Las playas dinámicas presentan una profundidad de cierre mayor de -2 m (Puerto Rico Vertical Datum 2002) PRVD02, mientras que en las playas estables ésta es menor de -2 m PRVD02.
- **Límite Hacia Tierra del Cambio en la Playa** - En todas las playas, el límite del cambio hacia tierra de la playa fue en general paralelo a la orilla y en algunas localizaciones, bordeaba la franja de vegetación. La altura de las olas cerca de la orilla en las playas dinámicas sobrepasaba 0.5 m, mientras que en las playas estables la altura de las olas era menor de 0.5 m o casi cero. En las playas dinámicas donde las olas eran más altas, el límite de cambio hacia tierra en la playa promedió elevaciones mayores de 1 m PRVD02, mientras que en las playas estables el promedio del cambio en elevación fue menor de 1 m PRVD02.
- **Posición de la Orilla** - Los rangos de la orilla en las playas dinámicas fueron mayores de 5 m, mientras que en las playas estables fueron menor de 5 m. (excepto en las Playas 3, 5 y 22). El Huracán María azotó Vieques el 20 de septiembre de 2017, generando olas altas y marejadas ciclónicas que fueron particularmente perjudiciales para la costa sur de Vieques.
- **Lluvia y Escorrentía Pluvial -** La precipitación en el 2015 fue menor a lo típicamente registrado pero fue típica posteriormente, con precipitación extrema en noviembre de 2016 y durante el paso de los Huracanes Irma y María en septiembre de 2017. Se concluyó que los cambios a las playas durante el BDI fueron típicos, y atribuidos meramente a olas, niveles de agua y corrientes, con cambios localizados en las playas cuando una serie de eventos extremos de precipitación ocurría dentro de un periodo corto.
- **Enterramiento y Movilidad de los MEC** - Por lo general, los MEC permanecen sobre la superficie en fondo duros, permanecen sobre la superficie o se auto-entierran parcialmente en fondos con hierba marina y se auto-entierran parcial o totalmente en fondos arenosos. Los MEC tienden a auto-enterrarse en fondos arenosos bajo condiciones de oleaje normal, dependiendo de la profundidad del agua. A mayor profundidad del agua, menor es la profundidad del enterramiento. Los MEC localizados en áreas costaneras de cambio (por ejemplo, hacia tierra desde la profundidad del cierre) tienden a enterrarse a mayor profundidad (más de un diámetro) debido a cambios en el fondo de toda la playa. Excepto en condiciones extremas de oleaje, los MEC localizados hacia el mar desde la profundidad del cierre (y generalmente hasta los que están hacia tierra desde la profundidad del cierre) no exhiben gran movilidad y los MEC enterrados permanecen enterrados.

Las herramientas conceptuales desarrolladas durante este BDI para estimar la profundidad del enterramiento y movilidad potencial de los MEC pudieran utilizarse en conjunto con mapas de las estructuras y cubierta del fondo marino para inferir la posible ubicación de MEC, explicar hallazgos de otros estudios y planificar futuras investigaciones, remediaciones y/o monitoreo a largo plazo.



NOTES

1. MOV = Municipality of Vieques.
2. NASD = Naval Ammunition Support Detachment.
3. VNTR = Vieques Naval Training Range.

FIGURE ES-1
Regional Location of Vieques, MOV, and Former VNTR and NASD
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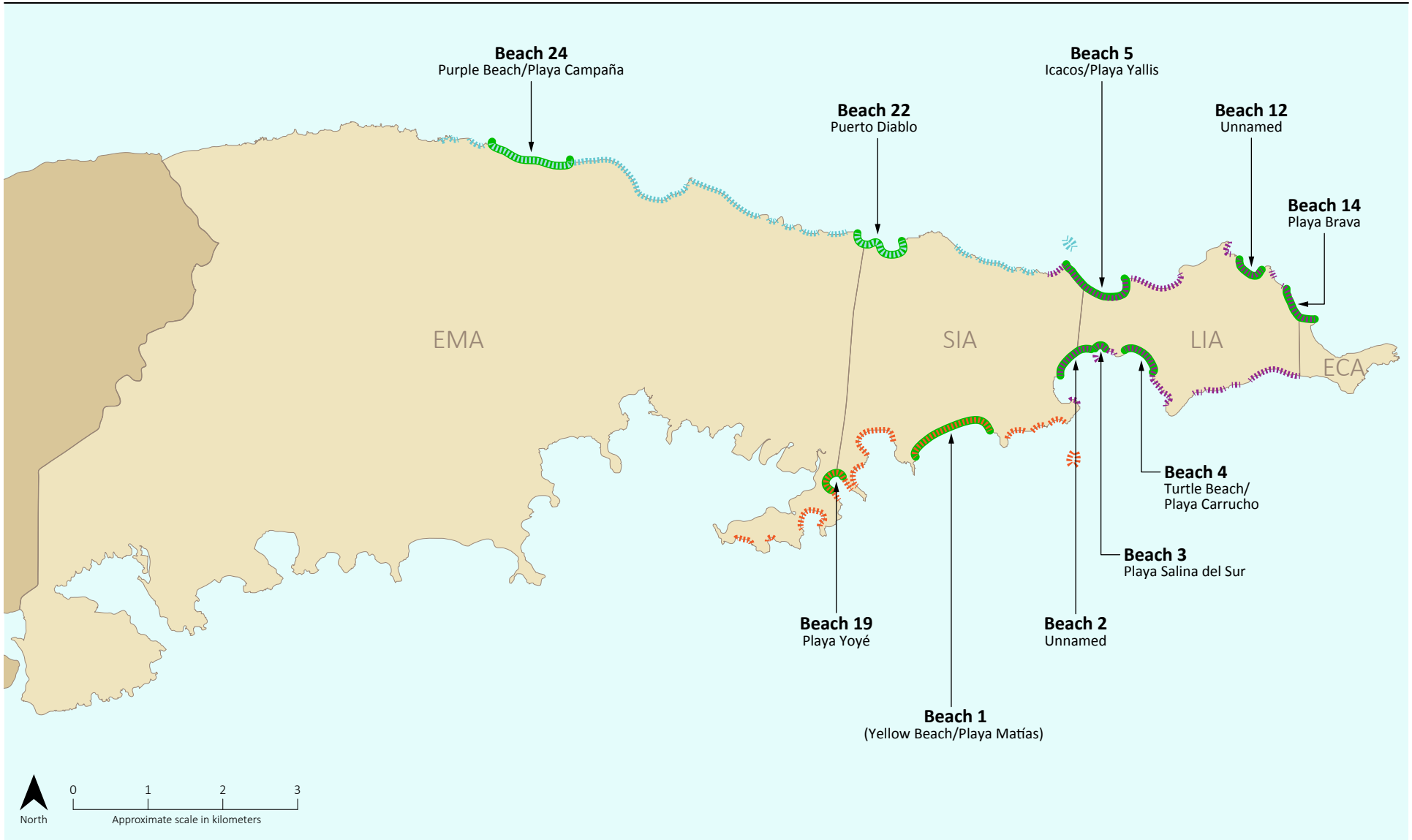
Vieques, Puerto Rico

Aerial reference 2017 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image © 2017 CNES/Airbus. Image © 2017 TerraMetrics.



LEGEND

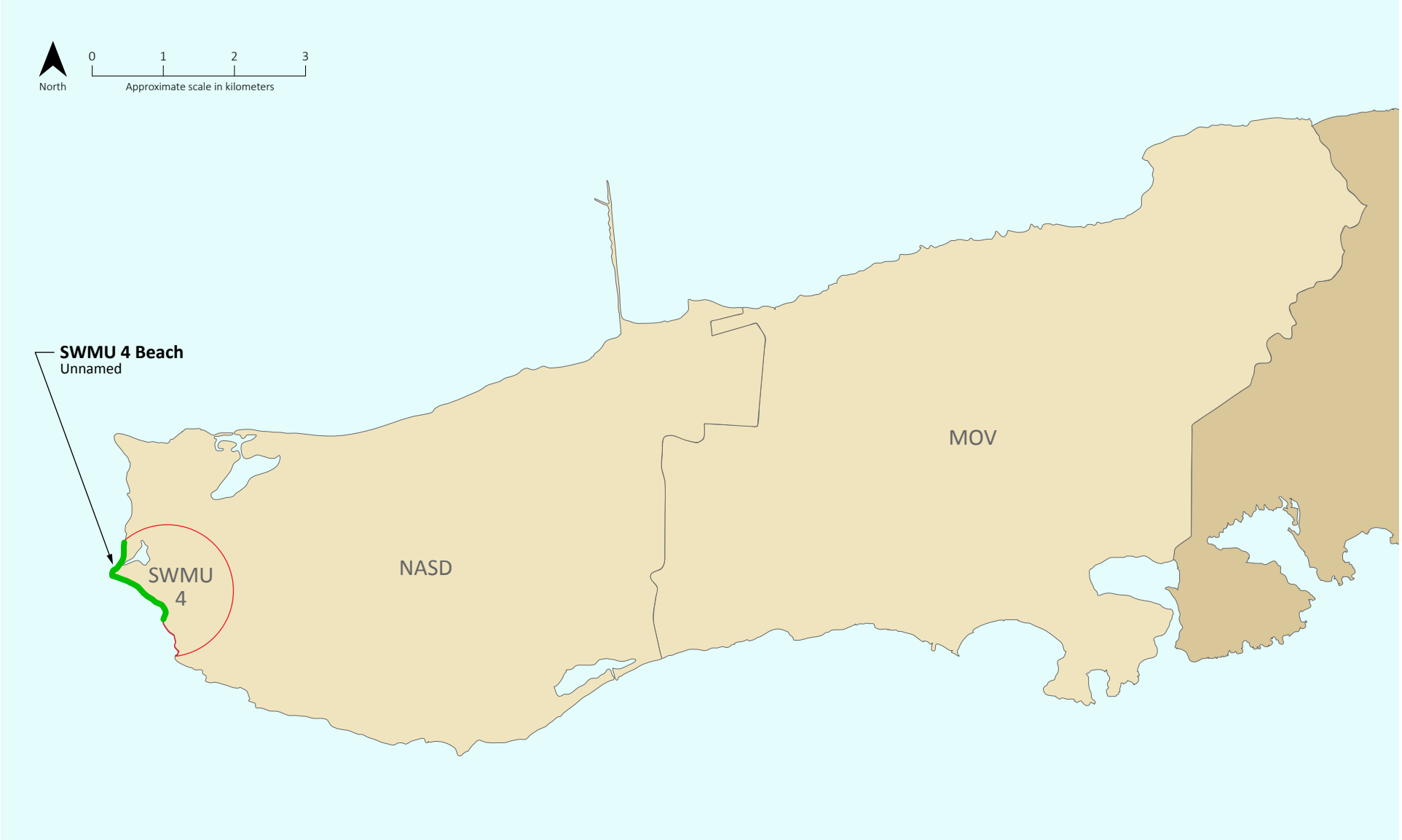
- BDI beach
- UXO-2 (LIA beaches)
- UXO-7 (EMA beaches and SIA north beaches)
- UXO-8 (SIA south beaches)

NOTES

1. ECA = Eastern Conservation Area.
2. EMA = Eastern Maneuver Area.
3. LIA = Live Impact Area.
4. SIA = Surface Impact Area.
5. VNTR = Vieques Naval Training Range.
6. UXO = Unexploded Ordnance.

FIGURE ES-2
Former VNTR Operational Areas, BDI Beaches, and UXO Sites
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial reference 2017 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image © 2017 CNES/Airbus. Image © 2017 Digital Globe.



LEGEND

BDI beach

NOTES

1. MOV = Municipality of Vieques.
2. NASD = Naval Ammunition Support Detachment.
3. SWMU = Solid Waste Management Unit.
4. UXO = Unexploded Ordnance.

FIGURE ES-3
Former NASD, SWMU 4, MOV, and BDI Beach
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Contents

Executive Summary ..... **iii**

Acronyms and Abbreviations ..... **xi**

1 Introduction **1-1**
1.1 Problem Definition 1-1
1.2 Objectives and General Approach 1-1

2 Site Background **2-1**
2.1 Former Naval Ammunition Support Detachment and Vieques Naval Training Range 2-1

3 Vieques Coastal and Marine Environment **3-1**
3.1 Coastal Features 3-1
3.2 Bathymetry 3-1
3.3 Metocean Conditions 3-1
3.3.1 Wind 3-1
3.3.2 Waves 3-2
3.3.3 Water Levels 3-2
3.3.4 Currents 3-3
3.3.5 Rainfall 3-3
3.3.6 Hurricanes 3-4
3.4 Bottom Structure and Cover 3-5

4 Summary of Field Activities **4-1**
4.1 Wave Measurements 4-1
4.2 Water Level Measurements 4-1
4.3 Rainfall Measurements 4-2
4.4 Beach Surveys 4-2
4.4.1 Beach Selection 4-2
4.4.2 Survey Approach and Methodology 4-3
4.5 Sediment Sampling and Analysis 4-3
4.6 MEC Surrogate Surveys 4-4
4.7 Metocean Field Observations 4-4
4.8 Third-party Metocean Data Collection 4-5

5 Results and Analysis **5-1**
5.1 Wave Climate 5-1
5.1.1 North Coast 5-1
5.1.2 East Coast 5-1
5.1.3 South Coast 5-1
5.1.4 Typicality Analysis 5-1
5.2 Storms 5-2
5.3 Water Levels 5-3
5.4 Rainfall 5-4
5.5 Beach Dynamics 5-4
5.6 MEC Surrogate Surveys 5-6

6 Summary and Conclusions **6-1**
6.1 BDI Summary 6-1
6.2 BDI Conclusions 6-1
6.2.1 Dynamics 6-2

6.2.2 Beach Profiles 6-2
6.2.3 Areas of Beach Change 6-2
6.2.4 Depth of Closure 6-2
6.2.5 Landward Limit of Beach Change 6-2
6.2.6 Shoreline Position 6-2
6.2.7 Hurricane Maria Shoreline Position Impacts 6-3
6.2.8 Rainfall and Surface Water Runoff 6-4
6.2.9 MEC Burial and Mobility 6-4

7 References 7-1

Appendixes

A Wave Measurements
B Rainfall Measurements
C Coordinate System and Benchmark Network
D Beach Surveys
E Sediment Sampling
F Munitions Surrogate Surveys
G Metocean Field Observations
H Third-party Metocean Data
I Wave Analyses
J Beach Dynamics Results and Analysis
K MEC Surrogate Surveys Results and Analysis
L Responses to Regulator Comments

Tables

3-1 Datums (m) at NOAA Water Level Stations Esperanza and Isabel Segunda
3-2 Significant Wave Height and Storm Surge at Vieques for Various Return Periods

4-1 Summary of Principal Characteristics of BDI Beaches
4-2 MEC Surrogate Types and Nominal Characteristics
4-3 Quantities of MEC Surrogates per Beach

5-1 Parameters of Storms that Passed Near Vieques During and After the BDI
5-2 Water Levels in Vieques Due to Storms During and After the BDI
5-3 Beach Dynamics Analysis for Beach 2 (Unnamed, UXO 2)
5-4 Beach Dynamics Analysis for Beach 3 (Playa Salinas del Sur, UXO 2)
5-5 Beach Dynamics Analysis for Beach 4 (Turtle Beach/Playa Carrucho, UXO 2)
5-6 Beach Dynamics Analysis for Beach 5 (Icacos, Playa Yallis, UXO 2)
5-7 Beach Dynamics Analysis for Beach 12 (Unnamed, UXO 2)
5-8 Beach Dynamics Analysis for Beach 14 (Playa Brava, UXO 2)
5-9 Beach Dynamics Analysis for Beach 22 (east) (Puerto Diablo, UXO 7)
5-10 Beach Dynamics Analysis for Beach 22 (west) (Puerto Diablo, UXO 7)
5-11 Beach Dynamics Analysis for Beach 24 (Purple Beach/Playa Campaña, UXO 7)
5-12 Beach Dynamics Analysis for Beach 1 (Yellow Beach/Playa Matías, UXO 8)
5-13 Beach Dynamics Analysis for Beach 19 (Playa Yoyé, UXO 8)
5-14 Beach Dynamics Analysis for Beach SWMU 4 (southwest-facing) (Unnamed)
5-15 Beach Dynamics Analysis for Beach SWMU 4 (west-facing) (Unnamed)

6-1 Summary of Beach Dynamics Results

Figures

ES-1 Regional Location of Vieques, MOV, and Former VNTR and NASD
ES-2 Former VNTR Operational Areas, BDI Beaches, and UXO Sites
ES-3 Former NASD, SWMU 4, MOV, and BDI Beach

1-1 Regional Location of Vieques, MOV, and Former VNTR and NASD
1-2 Former VNTR Operational Areas, BDI Beaches, and UXO Sites
1-3 Former NASD, SWMU 4, MOV, and BDI Beach

3-1 Bathymetry Around Vieques
3-2 Wave Refraction Pattern Around Vieques for Easterly Waves
3-3 Locations of NOAA Stations 9751639 Charlotte Amalie, 9752695 Esperanza, and 9752619 Isabel Segunda
3-4 Time History of Water Levels Predicted at NOAA Station 9752695 Esperanza for 2015
3-5 Still Water Level Anomaly at NOAA Station 9752695 Esperanza for 2015
3-6 Tracks of Historical Tropical Storms from 1950 to 2017
3-7 Tracks of Historical Hurricanes from 1950 to 2017
3-8 Geomorphological Structures Around the Former VNTR
3-9 Geomorphological Structures Around the Former NASD
3-10 Biological Cover Around the Former VNTR
3-11 Biological Cover Around the Former NASD

4-1 AWAC Sensor Locations at the Former VNTR
4-2 Location of NOAA Water Level Stations 9752695 Esperanza, and 9752619 Isabel Segunda
4-3 Location of Rainfall Gauge
4-4 Beaches Selected for the BDI
4-5 Deployment Locations of MEC Surrogates at the Former VNTR
4-6 Locations of Third-party Metocean Data Collection Stations within 40 nm from Vieques

5-1 Tropical Storm Erika Track
5-2 Hurricane Matthew Track
5-3 Hurricane Irma and Maria Tracks
5-4 Water Levels at NOAA Station 9752695 Esperanza in 2015 and 2016
5-5 Daily Rainfall in Vieques during the BDI
5-6 Monthly Rainfall in Vieques during the BDI
5-7 Annual Rainfall in Vieques during the BDI
5-8 Ephemeral Stream at the East End of Beach 1 (Transect 9)
5-9 Ephemeral Stream at the East End of Beach 1 (Transect 9)
5-10 Ephemeral Stream at the West End of Beach 24 (between Transects 8 and 9)
5-11 Surface Water Runoff Breach at Beach 22 (Transect 1)
5-12 Depth of Closure (yellow), Landward Limit of Beach Change (black), shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (Purple) at Beach 2
5-13 Depth of Closure (Yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 3
5-14 Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 4
5-15 Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 5
5-16 Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 12
5-17 Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 14
5-18 Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 22 (east)

5-19 Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 22 (west)
5-20 Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 24
5-21 Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 1
5-22 Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 19
5-23 Depth of Closure (yellow, broken line = uncertain), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at SWMU 4 (southwest-facing)
5-24 Depth of Closure (yellow, broken line = uncertain), Landward Limit of Beach Change (white), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at SWMU 4 (west-facing)
5-25 Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 2
5-26 Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 3
5-27 Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 4
5-28 Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 5
5-29 Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 12
5-30 Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 14
5-31 Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 22 (east)
5-32 Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 22 (west)
5-33 Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 24
5-34 Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 1
5-35 Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 19
5-36 Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at SWMU 4 (southwest-facing)
5-37 Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at SWMU 4 (west-facing)
5-38 Strafing Target at the East End of Beach 2 (Transect 7) Post-Maria
5-39 Ephemeral Stream at the West End of Beach 2 (Transect 1) Post-Maria
5-40 Laguna Anones Inlet at Beach 4 (Transect 6) Post-Maria
5-41 Laguna Puerto Diablo Overflow at Beach 22 (Transect 5) Post-Maria
5-42 Surface Water Runoff at Beach 22 (Transect 7) Post-Maria
5-43 Previously Buried Concrete Blocks at Beach 1, Exposed Post-Maria
5-44 Ephemeral Stream at SWMU 4 (Transect 1) Post-Maria
5-45 Laguna Boca Quebrada Inlet at SWMU 4 (Transect 15) Post-Maria

Acronyms and Abbreviations

Θ	Shields parameter
ρ_s	density of the surrogate
ρ_w	density of the water
τ	shear stress due to waves
A	wave orbital amplitude at the bottom
ASTM	American Society for Testing and Materials
AWAC	acoustic wave and current sensor
B	Holland's pressure profile parameter
B_d	depth of burial
BDI	Beach Dynamics Investigation
CARICOOS	Caribbean Coastal Ocean Observing System
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
cm	centimeter
CNC	computer numerical control
Cs	eddy viscosity
D	diameter of the cylinder
D_{50}	nominal diameter of the bottom sediment
deg	degrees
DGM	digital geophysical mapping
DOI	Department of the Interior
ECA	Eastern Conservation Area
EMA	Eastern Maneuver Area
EPA	Environmental Protection Agency
FFA	Federal Facility Agreement
FM	flexible mesh
f_w	wave friction coefficient
g	acceleration due to gravity
GPS	global positioning system
HAT	highest astronomical tide
HD	hydrodynamic model
Hs	significant wave height
IMERG	Integrated Multi-satellitE Retrievals for Global Precipitation Measurement
KC	Keulegan-Carpenter number
km	kilometer
LAT	lowest astronomical tide
LCG	longitudinal center of gravity
LIA	Live Impact Area
M	Manning number
m	meter
MEC	munitions and explosives of concern
metocean	meteorological and oceanographic
MHHW	mean higher high water

MLLW	mean lower low water
mm	millimeter
MOV	Municipality of Vieques
MP	mobility parameter
MSL	mean sea level
MWD	mean wave direction
NASD	Naval Ammunition Support Detachment
Navy	Department of the Navy
NDBC	National Data Buoy Center
NGS	National Geodetic Survey
nm	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NPL	National Priority List
NSRS	National Spatial Reference System
OB/OD	open burn/open detonation
OP	Observation Post
OPUS	Online Positioning User Service
P_n	neutral pressure
PREQB	Puerto Rico Environmental Quality Board
PRVD02	Puerto Rico Vertical Datum 2002
Re	Reynolds number
Rmax	radius to maximum wind
RTK	real time kinematic
SA	solar annual
SIA	Surface Impact Area
SSA	solar semi-annual
SW	spectral wave model
SWL	still water level
SWMU	Solid Waste Management Unit
Tp	peak wave period
USFWS	United States Fish and Wildlife Service
USVI	United States Virgin Islands
UTM	Universal Transverse Mercator
U_w	maximum undisturbed bottom orbital velocity
UXO	unexploded ordnance
VNTR	Vieques Naval Training Range
WAA	Wide Area Assessment

SECTION 1

Introduction

This Beach Dynamics Investigation (BDI) report presents the findings, conclusions, and recommendations of the BDI performed at 11 beaches located at the former Naval Ammunition Support Detachment (NASD) and the former Vieques Naval Training Range (VNTR) in Vieques, Puerto Rico (**Figures 1-1 through 1-3**). The BDI was conducted to augment the current understanding of the dynamic nature of the beach environment and its impact on the mobility of munitions and explosives of concern (MEC) and material potentially presenting an explosive hazard (MPPEH), by establishing correlations between measured beach changes, mobility of nearshore MEC, and meteorological and oceanographic (metocean) conditions.

This report was prepared under the Department of the Navy (Navy) Comprehensive Long-term Environmental Action–Navy (CLEAN) Contract N62470-16-D-9000, Contract Task Order 0004, for submittal to Naval Facilities Engineering Command (NAVFAC) Atlantic, Environmental Protection Agency (EPA) Region 2, the Commonwealth of Puerto Rico Environmental Quality Board (PREQB), the Commonwealth of Puerto Rico Department of Natural and Environmental Resources (PRDNER), and the United States Fish and Wildlife Services (USFWS). The Navy, EPA, PREQB, PRDNER, and USFWS work jointly to implement the Environmental Restoration Program.

The majority of BDI activities were conducted from October 2014 through February 2016 and included the measurement of waves, currents, and water levels along with collection of publicly available metocean data, periodic beach surveys to evaluate relative changes of the beaches, and tracking of nearshore (underwater) MEC surrogates. An additional beach survey was conducted in October and November 2017 and an additional surrogate tracking event was conducted in February 2018 to evaluate impacts from Hurricanes Irma and Maria. The BDI activities were conducted in accordance with the BDI Quality Assurance Project Plan (QAPP; CH2M, 2014).

The data and information collected during the BDI will be utilized to assist such things as future investigation and action planning, remedial action decision making, monitoring and operation and maintenance approach development.

1.1 Problem Definition

Beaches are continuously shaped by varying metocean conditions such as waves, currents, water levels, wind, and surface water runoff. Depending on the characteristics of these conditions, beach sediment can be transported in long- and cross-shore directions, and beaches and nearshore areas can erode or accrete in varying degrees. Because of beach accretion, surficial or buried MEC could be buried even deeper, potentially making it undetectable. Conversely, as a result of beach erosion, previously undetected MEC could become detectable and even exposed and transported by waves and currents.

Surface water runoff may also bury or expose or even transport and redistribute MEC from high to low elevation areas. At the same time, the hydrodynamic forces induced by waves and currents could intermittently bury, expose, and transport MEC and other metallic debris present in beaches and nearshore areas. The combination of these processes makes the burial and mobility of MEC a complex process that is important to study. The site-specific studies then foster predictive capabilities to better inform characterization and removal/remedial action determinations and long-term monitoring approaches.

1.2 Objectives and General Approach

The specific objectives of the BDI were to:

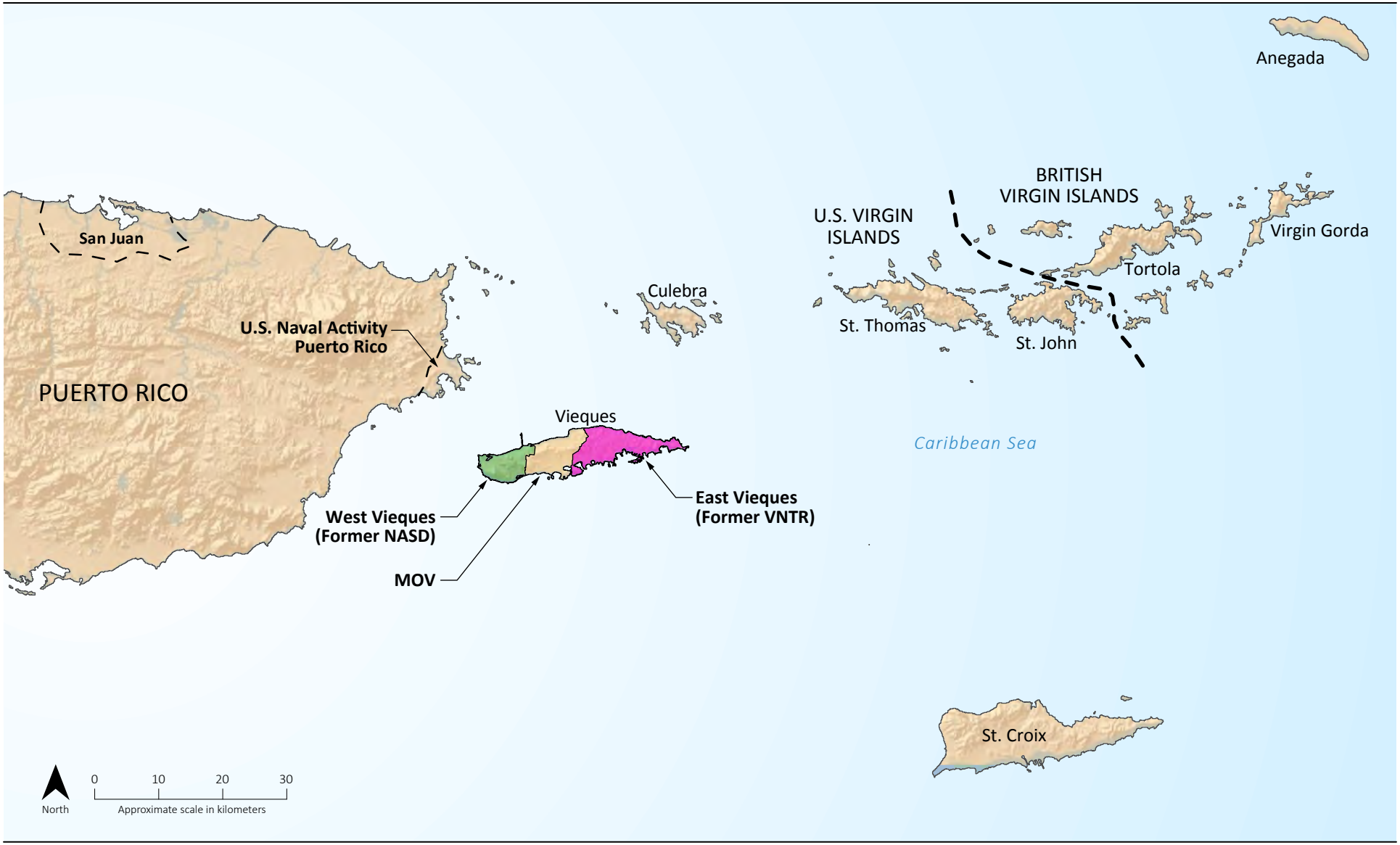
- Understand beach changes and burial and mobility of MEC during the range of metocean conditions present during the BDI
- Provide data and information that could be used to calibrate/validate numerical models to develop long-term predictions of beach changes, and burial and mobility of MEC in a wide range of metocean conditions

The BDI approach, as defined in the BDI QAPP, comprised the following activities:

- **Wave Measurements:** Continuous wave measurements at three locations, just offshore on the north, east, and south coasts of Vieques, to characterize wave conditions during the BDI and help assess their impacts on beach changes and burial and mobility of MEC
- **Water Level Measurements:** Concurrent water level measurements near Vieques collected from National Oceanic and Atmospheric Administration (NOAA) Stations, to help assess the impact of water levels on beach changes
- **Rainfall Measurements:** Continuous rainfall measurements at Camp Garcia to assess rainfall impacts on surface water runoff, beach changes, and burial and mobility of MEC
- **Beach Surveys:** Monthly at selected beaches, to measure and evaluate beach changes
- **Sediment Sampling and Analysis:** Quarterly, to determine beach sediment size and cross-shore distribution, and for input in potential MEC burial and mobility prediction models
- **MEC Surrogate Surveys:** Monthly, to evaluate burial and mobility of underwater MEC in the nearshore under the effect of beach changes and waves, currents, and water levels
- **Metocean Field Observations:** Performed during the beach surveys to gain a preliminary knowledge of conditions at the beaches as the BDI progressed and to verify estimates made by others
- **Third-party Metocean Data Collection:** Monthly, to characterize corresponding local and regional conditions during the BDI, and use in potential future studies

Field investigations were performed at the following beaches (**Figures 1-2 and 1-3**):

- UXO 2 (Live Impact Area [LIA] Beaches)
  - Beaches 2 (Unnamed), 3 (Playa Salinas del Sur), 4 (Turtle Beach/Playa Carrucho), 5 (Icacos/Playa Yallis), 12 (Unnamed), and 14 (Playa Brava)
- UXO 7 (North Eastern Maneuver Area [EMA]/Surface Impact Area [SIA] Beaches)
  - Beaches 22 (Puerto Diablo) and 24 (Purple Beach/Playa Campaña)
- UXO 8 (South SIA Beaches)
  - Beaches 1 (Yellow Beach/Playa Matías) and 19 (Playa Yoyé)
- Solid Waste Management Unit (SWMU) 4
  - Unnamed Beach

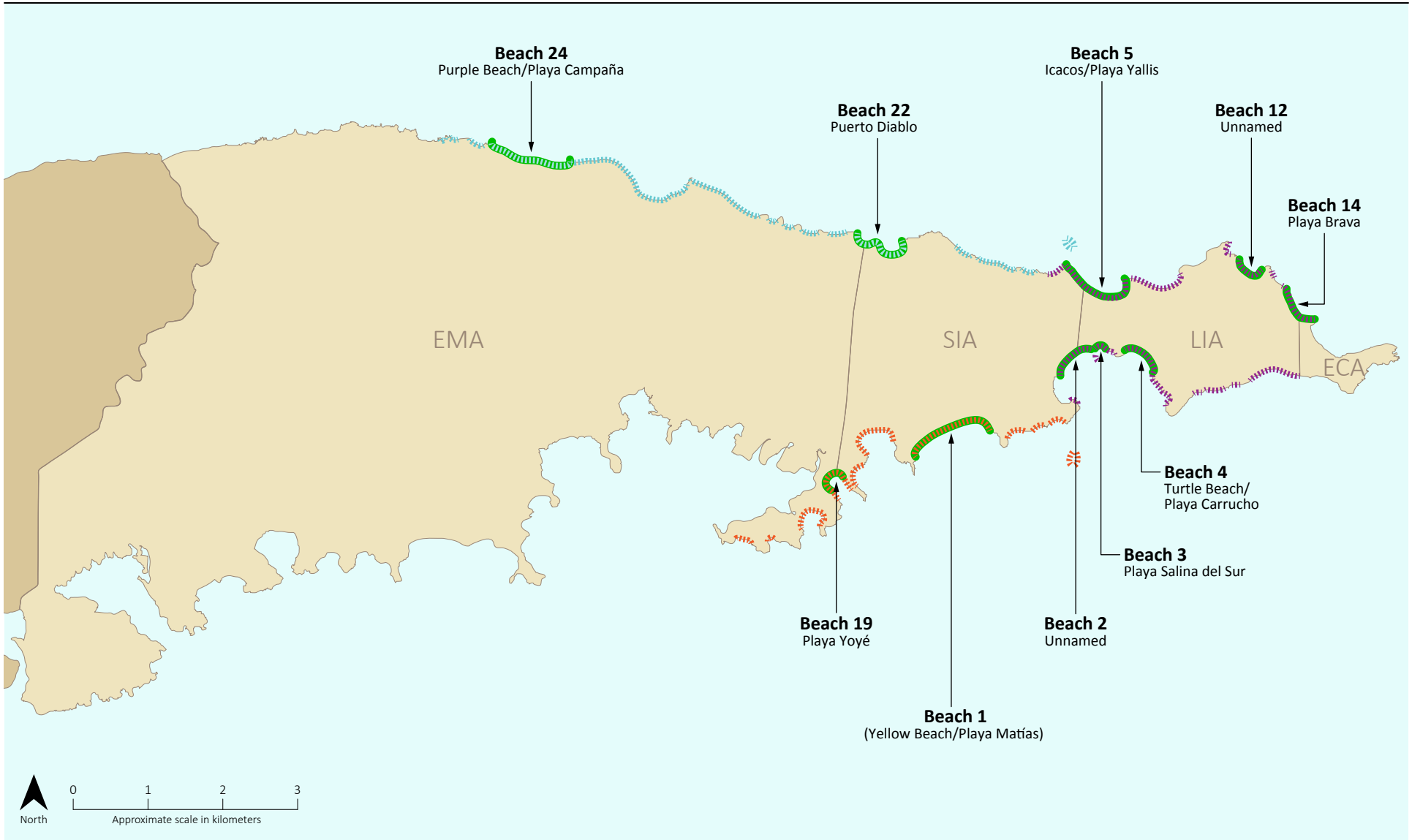


NOTES

1. MOV = Municipality of Vieques.
2. NASD = Naval Ammunition Support Detachment.
3. VNTR = Vieques Naval Training Range.

FIGURE 1-1
Regional Location of Vieques, MOV, and Former VNTR and NASD
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial reference 2017 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image © 2017 CNES/Airbus. Image © 2017 TerraMetrics.



LEGEND

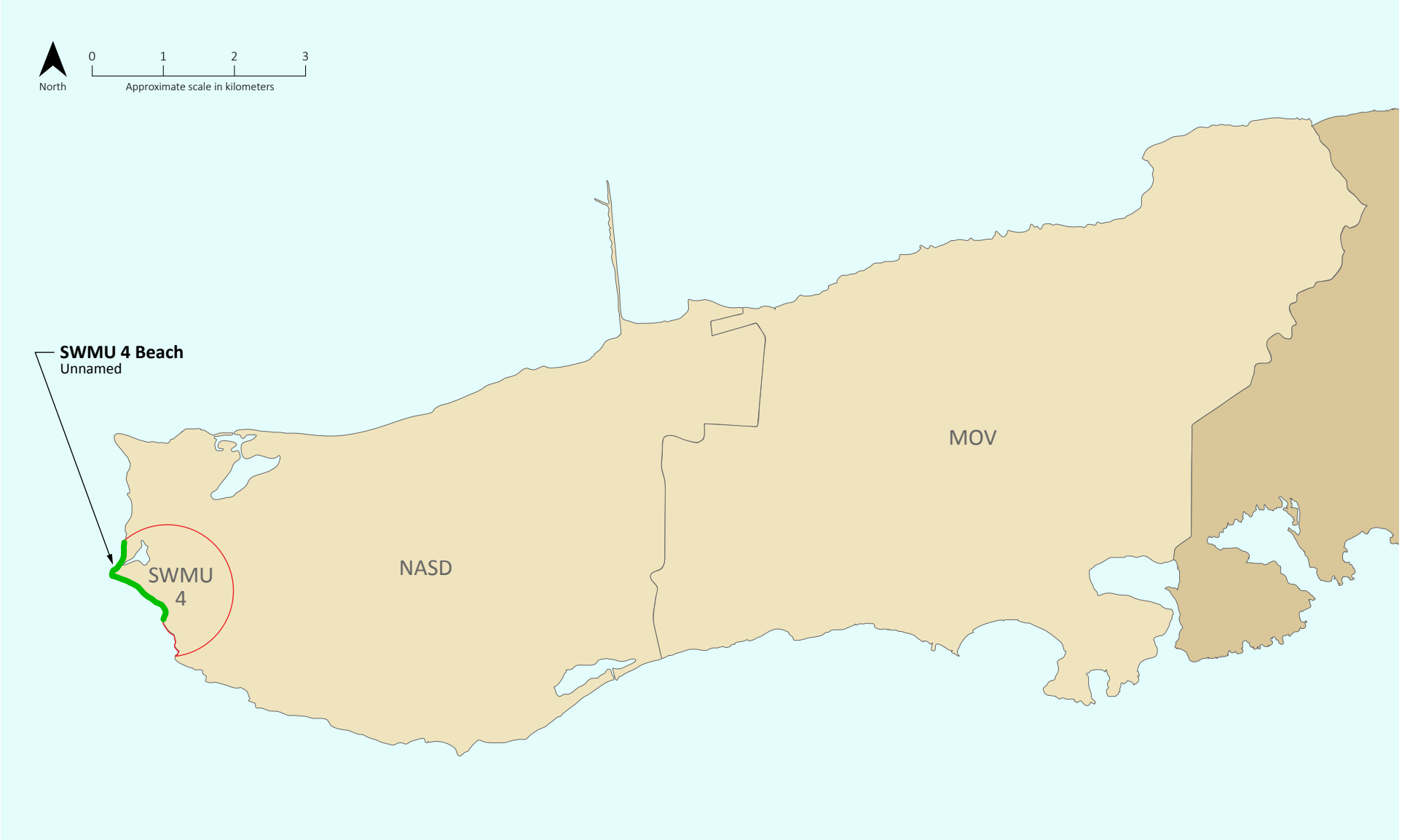
- BDI beach
- UXO-2 (LIA beaches)
- UXO-7 (EMA beaches and SIA north beaches)
- UXO-8 (SIA south beaches)

NOTES

1. ECA = Eastern Conservation Area.
2. EMA = Eastern Maneuver Area.
3. LIA = Live Impact Area.
4. SIA = Surface Impact Area.
5. VNTR = Vieques Naval Training Range.
6. UXO = Unexploded Ordnance.

FIGURE 1-2
Former VNTR Operational Areas, BDI Beaches, and UXO Sites
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial reference 2017 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image © 2017 CNES/Airbus. Image © 2017 Digital Globe.



LEGEND

BDI beach

NOTES

1. MOV = Municipality of Vieques.
2. NASD = Naval Ammunition Support Detachment.
3. SWMU = Solid Waste Management Unit.
4. UXO = Unexploded Ordnance.

FIGURE 1-3
Former NASD, SWMU 4, MOV, and BDI Beach
Beach Dynamics Investigation Report
Vieques, Puerto Rico

SECTION 2

Site Background

Vieques is located in the Caribbean Sea approximately 7 miles southeast of the eastern tip of the main island of Puerto Rico and 20 miles southwest of St. Thomas, United States Virgin Islands (USVI; **Figure 1-1**). Vieques is approximately 20 miles long and 4.5 miles wide, and has an area of approximately 33,088 acres (51 square miles).

The Navy purchased large portions of Vieques in the early 1940s to conduct activities related to military training. The former Atlantic Fleet Weapons Training Area (AFWTA) was historically divided into two portions – the NASD and VNTR. Site operations on the western end of Vieques (former NASD) consisted mainly of ammunition loading and storage, vehicle and facility maintenance, and open burn/open detonation (OB/OD). The eastern end of Vieques (former VNTR) was used for various aspects of naval gunfire training, including air-to-ground ordnance delivery and amphibious landings, as well as housing the main base of operations for these activities, Camp Garcia.

The former NASD was apportioned and transferred to the Department of the Interior (DOI), the Municipality of Vieques, and the Puerto Rico Conservation Trust in 2001, in accordance with Public Law 106-398. The property owned by DOI is managed by USFWS as part of the Vieques National Wildlife Refuge (VNWR). The former VNTR was transferred to DOI to be operated by USFWS as part of the VNWR in 2003, in accordance with Public Law 107-107. The offshore territorial waters are under the jurisdiction of the Commonwealth of Puerto Rico and extend 9 nautical miles (nm) from the coast of Vieques.

On February 11, 2005, Vieques was placed on the National Priority List (NPL) as the former AFWTA - Vieques, which required all subsequent environmental restoration activities for Navy Installation Restoration sites on Vieques to be conducted under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) unless and until removed from CERCLA authority. The Navy, DOI, EPA, and PREQB executed a Federal Facility Agreement (FFA) on September 7, 2007 that established the procedural framework and schedule for implementing the CERCLA response actions for Vieques.

2.1 Former Naval Ammunition Support Detachment and Vieques Naval Training Range

The former NASD consists of approximately 8,100 acres (**Figures 1-1 and 1-3**). SWMU 4, which was formerly used as an OB/OD area for the thermal destruction and open detonation of retrograde and surplus munitions, fuels, and propellants, is located within the western portion of the former NASD.

The former VNTR consists of approximately 14,600 acres and is divided into four separate operational areas that from west to east comprise the 11,000-acre EMA, the 2,500-acre SIA, the 900-acre LIA, and the 200-acre Eastern Conservation Area (ECA), as shown in **Figures 1-1 and 1-2**.

- EMA – established in 1947 to provide military maneuvering areas and ranges for training in amphibious landings, small arms fire, artillery and tank fire, shore fire control, and combat engineering tasks
- SIA – established in the 1950s when several Marine artillery targets were constructed; in 1969, a bullseye target was constructed and used for inert bombing
- LIA – established in 1965, where several targets were maintained for aerial bombing including old tanks and vehicles, a simulated railroad tunnel, simulated ammunition dump, simulated fuel farm, a simulated airstrip, two simulated surface-to-air missile sites, and a strafing target; several point and area targets were used for ships to practice naval gunfire support; one bullseye target used for inert bombing; and an OB/OD area was used for treatment of retrograde ordnance and open burning of propellants and pyrotechnics
- ECA – established as a conservation area and not used as an operational area for munitions; however, the site is located adjacent to the LIA

Following cessation of military operations on the former NASD and VNTR, the Navy subdivided the former operational areas into smaller parcels based on considerations such as historic use, geographic features, and land use. The parcels, referred to as UXO sites, were delineated in such a way to make them more manageable for the purposes of prioritization, munitions removal, site characterization, and decision making (**Figures 1-2 and 1-3**).

SECTION 3

Vieques Coastal and Marine Environment

The general setting of the coastal and marine environment at Vieques, summarized in the subsections that follow, is based on information obtained mainly from the following sources: Bauer et al. (2008), Geo-Marine Inc. (2005), Morelock et al. (2014), and the Caribbean Fishery Management Council (2004). Summaries and adaptations of this information are complemented with observations made during a site visit performed by CH2M between March 11 and 15, 2013 (CH2M, 2014). The general setting described by these sources is consistent with observations and data collected during the BDI.

3.1 Coastal Features

Extending approximately 20 miles long and 4.5 miles wide, Vieques is one of the principal islands offshore of Puerto Rico's main island. Its coastline is very irregular and surrounding bathymetry includes steep shelves and shallow reefs. Coastal features along its north and south coasts include fringing, patch and barrier reefs, mangroves, headlands, islands, bays, and sandy pocket beaches. The clarity and quality of its coastal waters contribute to the presence of coral reefs and provide favorable conditions for marine life.

3.2 Bathymetry

A review of existing bathymetry data from various sources was documented in the BDI QAPP (CH2M, 2014); a general summary of the bathymetry around Vieques is provided below. **Figure 3-1** shows the bathymetry contours around Vieques.

The bathymetry around Vieques differs markedly between the north and south coast. North of the island, the seafloor is generally uniform and shallow, interrupted only by reefs and a sand and gravel shoal, the Escollo de Arenas, on the northwestern end of the island. The seafloor slopes gently from the shore to a depth of approximately 15 meters (m), and then reaches a broad 25 m deep shelf that extends to the north and west.

The south coast is characterized by a longshore 15 to 20 m deep coral reef approximately 2 to 3 kilometers (km) offshore. South of the reef, there is a steep slope where the seafloor drops abruptly to depths over 1,000 m. Within the area of interest for the BDI, a 25-m deep trough separates the south coast from the offshore reef. The south coast features a series of bays, islands, and pocket beaches and the seafloor slopes gently to a depth of approximately 15 m at the edge of the trough. The bathymetry to the east of the island features a 25 to 45 m depth transition between the shallow shelf on the north and the edge of the steep slope to the south.

3.3 Metocean Conditions

3.3.1 Wind

Vieques lies along the northern edge of the Trade Wind belt, which circles the globe from east to west. Locally, these surface winds are associated with the mid-latitude high pressure cell, whose center is periodically displaced along the Bermudas-Azores latitude band. This clockwise rotating, high surface pressure system generates easterly winds over the Caribbean. The actual wind direction varies from northeast to east, depending on the season. From November to February/March, east to northeast 10 to 15-knot winds are typical. After February/March the typical 10 to 15-knot wind is more persistent from the east, dying down toward the summer. In the summer, the typical wind is from the east at 5 to 10 knots. Wind from the southeast is not very common in Vieques, and it is generally associated with the passage of storms.

Wind is the forcing mechanism of waves, and the wave climate that drives beach changes in Vieques is the result of local wind, as well as wind generated by distant weather systems in the Caribbean Sea and the North Atlantic Ocean. A good knowledge of the wind climate is important to understand the wave climate in Vieques.

3.3.2 Waves

The most frequent wave condition around Vieques consists of easterly waves generated by the Trade Winds. As these waves approach the coast they are transformed due to the proximity of the bottom, refracting, and gradually aligning their fronts with the depth contours, and shoaling and breaking in shallow water. **Figure 3-2** shows typical wave refraction patterns around Vieques for easterly waves.

The wave climate just offshore Vieques consists of easterly 1 to 2 m waves with periods in the range of 5 to 10 seconds. The east, windward facing coasts are fully exposed to these waves, and the west coast of Vieques generally exhibits smaller waves.

As noted previously, from November to February/March, winds are predominant and stronger from the northeast, and therefore the north coast of Vieques is more exposed to waves and the south coast is more protected. During these winter months, stronger than usual 25 to 30-knot winds from the northeast generated by storms and cold fronts farther north, produce 3 to 3.5 m, 12 to 16-second period between each of the waves that often reach the north coast of Vieques.

Beach changes are driven by waves in the nearshore, and wave-induced flow is one of the main mechanisms of MEC burial and mobility. A good knowledge of the wave climate in the nearshore is important to understand the magnitude, distribution, and seasonality of the beach changes in Vieques and the MEC burial and mobility processes.

3.3.3 Water Levels

Water levels are forced by different mechanisms and feature different time scales. At one end of the time scale, the mean sea level (MSL) exhibits variations in a time scale of years and would increase as climate change materializes, also in a time scale of years. The still water level (SWL), which oscillates about the MSL, has a time scales of hours and is forced by the astronomical tide and metocean phenomena such wind, waves, and atmospheric pressure changes. In addition, solar radiation, which affects the thermal expansion of the ocean, varies throughout the year, and has a time scale of months. Water level gauges, commonly referred to as tide gauges, measure the SWL, which is the astronomical tide plus the effects of all metocean phenomena. At the NOAA Station 9751639 Charlotte Amalie USVI, shown in **Figure 3-3**, the closest water level station to Vieques where the MSL trend has been computed, the MSL trend shows an increase rate of approximately 2 millimeters (mm)/year.

Throughout the northeastern Caribbean, astronomical tides exhibit a complex behavior. Along the south coast of Vieques, the astronomical tide is principally diurnal (one cycle per day), while along the north coast, the tide is semidiurnal (two cycles per day). The astronomical tide range along the south and north coasts is relatively small and in the order of 0.20 and 0.40 m, respectively. NOAA operates two water level stations in Vieques, 9752695 at Esperanza on the south coast and 9752619 at Isabel Segunda on the north coast (**Figure 3-3**). **Table 3-1** lists the water level datums at these stations for the 1983-2001 epoch.

In addition to the gravitational forces induced by the moon and the sun, water levels are driven by the effects of solar radiation which in turn affects the thermal expansion of the ocean. These are characterized by a few long period harmonic constituents of which the solar annual (SA) and solar semi-annual (SSA) constituents are the most relevant. At Vieques, the SA constituent has an amplitude of 0.06 m, while the SSA is insignificant. Representative of a normal year, **Figure 3-4** shows the time history of predicted water levels at NOAA Station 9752695 Esperanza for 2015. The MSL shows a minimum of -0.06 m at the end of the winter in March, and maximum of 0.06 m at the end of summer in September. At 0.12 m, the range of the MSL is significant, considering that the tide range (mean higher high water [MHHW] – mean lower low water [MLLW]) at Esperanza is approximately 0.20 m.

Water levels around Vieques, like at most locations in the Caribbean, are affected by wind and the waves during storm events, and this effect is manifested by an increase of the SWL, termed storm surge. The inspection of NOAA water level records showed that the highest water level measured at Esperanza was 0.46 m on August 22, 2011 at 01:06 local time during Hurricane Irene. The predicted water level for that day and time, accounting only

for the astronomical tide, was 0.03 m, resulting in a storm surge of 0.43 m. According to the Caribbean Disaster Mitigation Project (2000), the 0.43 m storm surge generated by Hurricane Irene had a 10-year return period. The lowest water level measured at Esperanza was -0.31 m at 23:00 local time on January 27, 2006. This low water level is consistent with the predicted -0.24 m.

The inspection of predicted and measured water levels at NOAA water level stations in the region (Puerto Rico and USVI) shows a notable phenomenon where the measured water levels consistently exceed the predicted. The difference between the measured and the predicted water level (or SWL), termed the anomaly, varies throughout the year. **Figure 3-5** shows the SWL anomaly for 2015 at NOAA Station 9752695 Esperanza; the SWL anomaly averages approximately 0.10 m and could reach up to 0.20 m. This anomaly is significant considering that the tide range (MHHW – MLLW) at Esperanza is 0.22 m. The only known metocean event in 2015 that produced a noticeable anomaly was the storm surge due to Tropical Storm Erika on August 28 which, due to its relative short 1-day duration, is shown as a spike in **Figure 3-5**, with a magnitude of 0.22 m.

The SWL anomaly could possibly be caused by mesoscale eddies (e.g., large whirlpools of water with diameters in the order of hundreds of km) which are formed by the interaction between the Caribbean Current, which flows in the southeast to northwest direction, and nearby islands (e.g., Saint Croix) and large underwater topographic features such as the Aves and Beata Ridges to the southeast and southwest of Vieques, respectively.

Beach changes due to waves vary depending on the water level, because water levels change the location of wave action on the beach slope, and the water depth which affects wave transformation and resulting waves in the nearshore. Due to their effect on the water depth, water levels also affect the ability of the waves to bury and transport MEC. A good knowledge of the range of water levels and, in particular, the extremes resulting from storms or anomalies like mesoscale eddies, are important for the understanding of the beach changes in Vieques, and the MEC burial and mobility processes.

3.3.4 Currents

Current patterns in the Caribbean Sea are highly variable, both spatially and temporally. This variability is a function of the bathymetry, wind forcing, and the tide. The average current pattern around Puerto Rico, and the U.S. and British Virgin Islands archipelago is in an east to west direction and mainly driven by the tide and wind. These waters join the general western flow of the Caribbean Current towards the Yucatan Strait.

There are limited data available on current patterns around Vieques. However, previous studies (GMI, 2005) have indicated that surface currents around Vieques are driven mainly by the prevailing trade winds and that prevailing surface currents at the eastern end of Vieques flow east to west at approximately 0.10 m/second (0.20 knots) along the north and south coasts. This is consistent with rule-of-thumb estimates of 2 to 3% of the wind speed which would result in wind-induced currents in the order of 0.20 to 0.45 knots for the typical 10 to 15-knot easterly winds. Given its relatively low range, in the order of 0.20 to 0.40 m, the tide does not contribute significantly to the current.

The east to west wind-induced current sets a longshore drift that moves suspended sediments in the same direction. At the northwest end, the convergence of this westward current with northward currents along the Pasaje Vieques (the passage between Vieques and Puerto Rico) formed the peculiar Escollo de Arenas shoal.

Currents transport sediments, those in suspension (by advection) and on the bottom (bed load), to drive MEC burial and mobility. A good knowledge of the relative importance of the various mechanisms (tide, wind, and waves) and the currents these induce is important for the understanding the sediment transport process that shapes beaches in Vieques, and the MEC burial and mobility processes.

3.3.5 Rainfall

Rainfall in Vieques varies monthly. The driest months are usually January through April. The lowest amount of rainfall occurs in February, averaging about 64 mm. Thereafter, amounts of monthly rainfall increase to peak in October at about 191 mm. May, with an average rainfall of 191 mm, is the exception to this gradual increase in rainfall. The mean annual rainfall on Vieques is 1150 mm. The east end of Vieques receives on average 640 mm of

rainfall per year, and the west end 1250 mm. In September 2003, Vieques received 660 mm of rainfall in 36 hours. That is considered the 100-year event (USFWS, 2007).

Surface water runoff due to rainfall in Vieques could influence beach changes and MEC burial and mobility, mainly in the backshore and shoreline areas. Surface water runoff may also expose previously undetected MEC as well as redistribute MEC from high to low elevation areas. In addition, rainfall could increase water levels in lagoons and ephemeral streams, which could then breach beach berms. A good knowledge of the rain climate in Vieques is important for the understanding of if and how this mechanism influences beach changes, and the MEC burial and mobility processes.

3.3.6 Hurricanes

Vieques is on the path of Atlantic tropical storms and hurricanes, and it has been affected by both in recent history. From June to November, the high sea surface temperatures and favorable atmospheric conditions in the North Atlantic Ocean allow the development of tropical lows into tropical depressions, tropical storms, and hurricanes. These storms track predominantly from southeast to northwest. **Table 3-2** shows estimates of significant wave heights (Hs) and storm surges at Vieques, for various return periods, according to the Caribbean Disaster Mitigation Project (2000). These could result from the passage of tropical storms and hurricanes (both referred to as storms, herein), depending on their proximity and intensity.

Figure 3-6 and **Figure 3-7** show the tracks of 9 tropical storms and 8 hurricanes, respectively, for the period from 1950 to 2017, and passing within a 50- nm radius of Vieques. The year 1950 was chosen as the start of the period of record because that is approximately the time when Navy activities began in Vieques, and when better technologies began to be available to define more accurately storm characteristics (e.g., tracks, pressure, wind speed, etc.). For the 68 years of record and for the 50-nm radius around Vieques, the frequency is approximately one tropical storm every 8 years, and one hurricane every 9 years. An inspection of historical records showed that nearly 50% of the storms occur in September and 25% in August.

Hurricane David in 1979, and Hurricane Hugo in 1989 were violent hurricanes that severely impacted Vieques' coastline and marine habitats. According to Lizano (1991), Hurricane David passed approximately 90 nm to the south of Vieques in an east to west direction and generated southeasterly 3 m significant wave heights along the south coast. Rodriguez et al. (1994) reports that Hugo, with winds greater than 150 mph, was the most intense hurricane to impact Puerto Rico since 1956. Hugo traveled in a southeast to northwest direction and made landfall in Vieques. Observation of storm-swash debris indicated that 2 to 3 m water levels in the Pasaje Vieques were reached. The estimated storm surge on the southeast end of Vieques was in the order of 1 m, and wave runup approximately 2.5 m, generating a total water level of approximately 3.5 m relative to MSL. Wind- and wave-induced currents generated by Hugo were sufficiently strong to scour sediments from around seagrass roots, tore up extensive areas of seagrass, and deposited the debris on the south coast. Rodriguez et al. (1994) did not provide information about wave heights, but correlating Hugo's estimated 1 m storm surge along Vieques south coast with wave heights in **Table 3-2** it can be inferred that waves in deep water may have reached 6 to 7 m.

In 2017, after the completion of the BDI, Vieques was impacted by two hurricanes within two weeks. Both hurricanes tracked in a southeast to northwest direction. Hurricane Irma, a Category 5 hurricane, passed approximately 35 nm to the northeast of Vieques on September 6, and Hurricane Maria, a Category 4 hurricane, passed approximately 10 nm to the southwest of Vieques on September 20.

Hurricane Maria made landfall on the east coast of Puerto Rico at Yabucoa, approximately 15 nm (30 km) to the west-southwest of Vieques across the Pasaje Vieques with sustained winds of about 130 knots (240 km/hour). The strong winds, track direction and location relative to Vieques made Maria one of the most devastating hurricanes to hit Vieques in recent times, likely more devastating than Hugo. Hurricane Maria generated high waves and storm surge which were particularly damaging on Vieques' south coast. As Maria approached Vieques from the southeast and progressed to the northwest, its counterclockwise wind circulation generated northeasterly winds and waves on the north coast first, then easterly and finally southerly wind and waves on the east and south coasts, respectively. The direction and location of the hurricane track relative to Vieques produced longer wind durations from the southerly sector which resulted in high waves and storm surge affecting the south coast for

longer than elsewhere around Vieques. Post-BDI analyses, described in Section 5, showed that significant wave heights just offshore the BDI beaches were in the order of 6 m, and storm surge approximately 1 m.

Hurricanes, as well as tropical storms, are episodic events that generate atypical high water levels and waves which, depending on proximity, direction, and intensity, can cause significant beach and bottom changes and burial and mobility of MEC. A good knowledge of the frequency of occurrence and characteristics of hurricanes and tropical storms that had impacted or could impact Vieques is important to understand the potential consequences on these phenomena.

3.4 Bottom Structure and Cover

The contrasting bathymetry, bottom structure, and cover on the north and south sides of Vieques are reflected in the distribution of benthic habitats and associated biological communities. Seagrass communities, which are generally limited to shallow depths and protected, low wave energy regions, are widespread northwest of Vieques where the water depth is shallow and wave conditions are relatively calm. In contrast, hard bottom habitats are typified by higher topographic complexity than seagrass and other soft bottom habitats. For example, the areas of highest complexity around Vieques highlight slopes and areas of reef and hard bottom. These features include numerous patch reefs north of Vieques, and barrier reefs extending along the edge of the steep slope on the south side of the island.

Descriptions of bottom structure and cover for Vieques were obtained from NOAA’s Vieques Biogeography Integrated Online Mapper (BIOMapper, 2016). The Vieques BIOMapper provides benthic habitat maps of the nearshore marine environment created in 2008 by visual interpretation of remotely sensed imagery by NOAA's Center for Coastal Monitoring and Assessment Biogeography Branch in partnership with NOAA's Office of Response and Restoration. Specific details about the development of the Vieques BIOMapper are described by Bauer et al. (2010). The maps provide spatially-explicit information on:

- Broad geographic zone
- Geomorphological structure type
- Dominant biological cover
- Percent of live coral cover
- Percent of hard bottom

A total of 350 square kilometers (km^2) of bottom features around Vieques were mapped. Soft bottoms, constituted by unconsolidated sediments like sand and mud account for 66.6% of the mapped area and hard bottoms account for 33.4%.

Figure 3-8 and **Figure 3-9** show the geomorphological structures around the former VNTR and NASD, respectively. On the south coast of the former VNTR, the nearshore bottoms are mainly unconsolidated sediments (e.g., sand or mud), transitioning to the east coast where the bottom is mainly reef with a 0% to < 10% of live coral. The north coast exhibits a mix of unconsolidated and hard bottoms. At the former NASD, the nearshore bottoms are mainly unconsolidated sediments (sand), except for a stretch of the south coast where the bottom is mainly reef with a 0% to < 10% of live coral.

Algae is the dominant cover on the hard bottom areas, while seagrass dominates the soft bottom areas. The percent of live coral cover was <10% for 93% of the mapped area, while for the remainder 7% the percent of live coral is 10% to < 50%. **Figure 3-10** and **Figure 3-11** show the biological cover around the VNTR and NASD, respectively.

A good knowledge about the distribution and type of bottom structure and cover is important for identification and delineation of environmentally sensitive areas, and areas of potential MEC burial and mobility.

TABLE 3-1
Datums (m) at NOAA Water Level Stations Esperanza and Isabel Segunda
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Datum	Esperanza [a]	Isabel Segunda [b]
Highest Water Level	0.46	- - -
Highest Astronomical Tide (HAT)	0.22	0.33
Mean Higher High Water (MHHW)	0.11	0.20
Mean High Water (MHW)	0.10	0.13
Mean Sea Level (MSL)	0.00	0.00
Puerto Rico Vertical Datum 2002 (PRVD02)	-0.02	- - -
Mean Low Water (MLW)	-0.11	-0.13
Mean Lower Low Water (MLLW)	-0.12	-0.18
Lowest Astronomical Tide (LAT)	-0.27	-0.32
Lowest Water Level	-0.31	- - -

a. NOAA Station 9752695, tidal datum analysis period: 04/01/2007 - 03/31/2009, and 03/01/2010 - 02/28/2013

b. NOAA Station 9752619, tidal datum analysis period: 08/01/2009 - 06/30/2010

TABLE 3-2

Significant Wave Height and Storm Surge at Vieques for Various Return Periods

Beach Dynamics Investigation Report

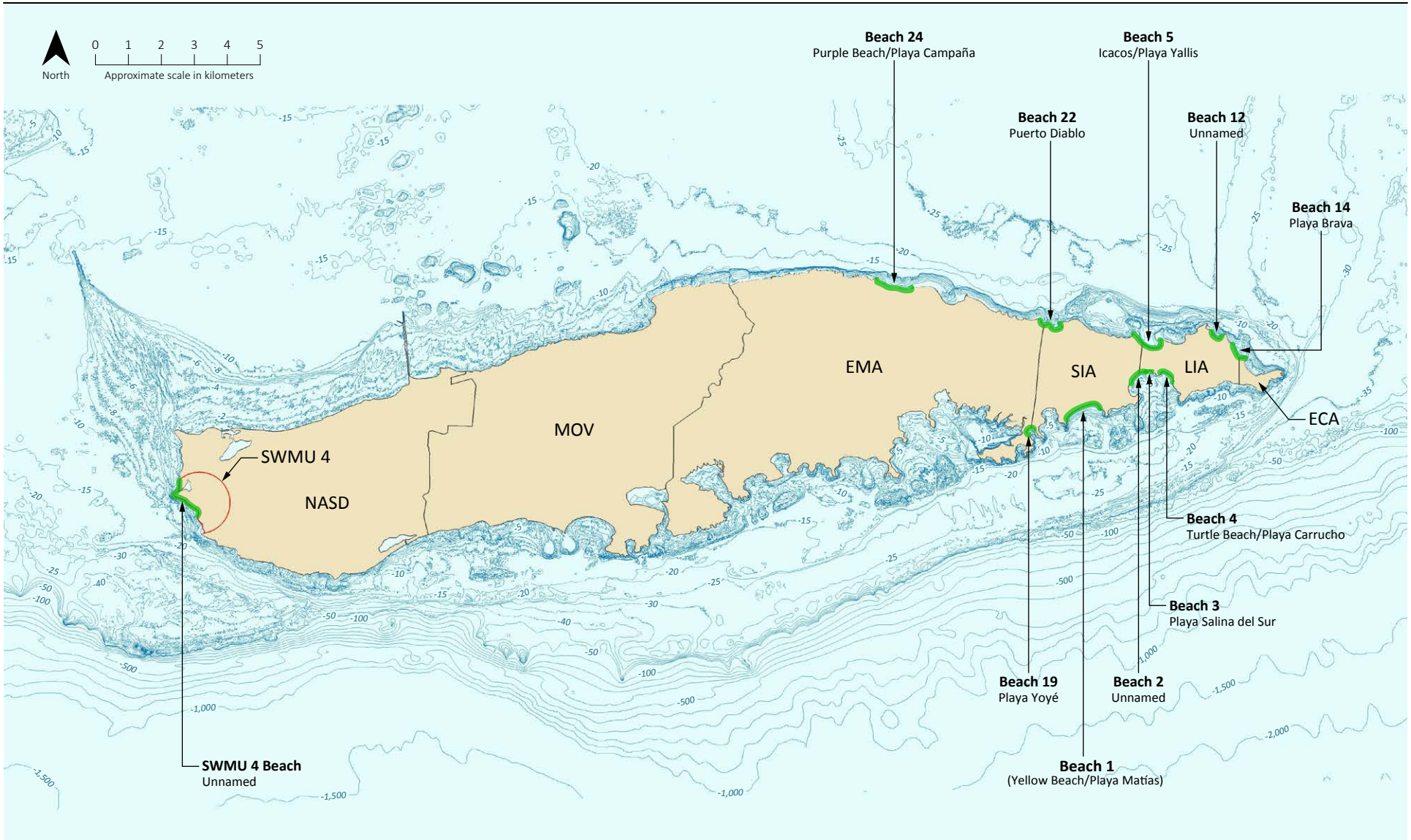
Vieques, Puerto Rico

Return Period (years)	Hs (m)	Storm Surge (m)
10	4.7	0.4
25	5.2	0.6
50	6.0	1.0
100	7.5	1.2

m = meters

Note: Data obtained from the Caribbean Disaster Mitigation Project (2000)

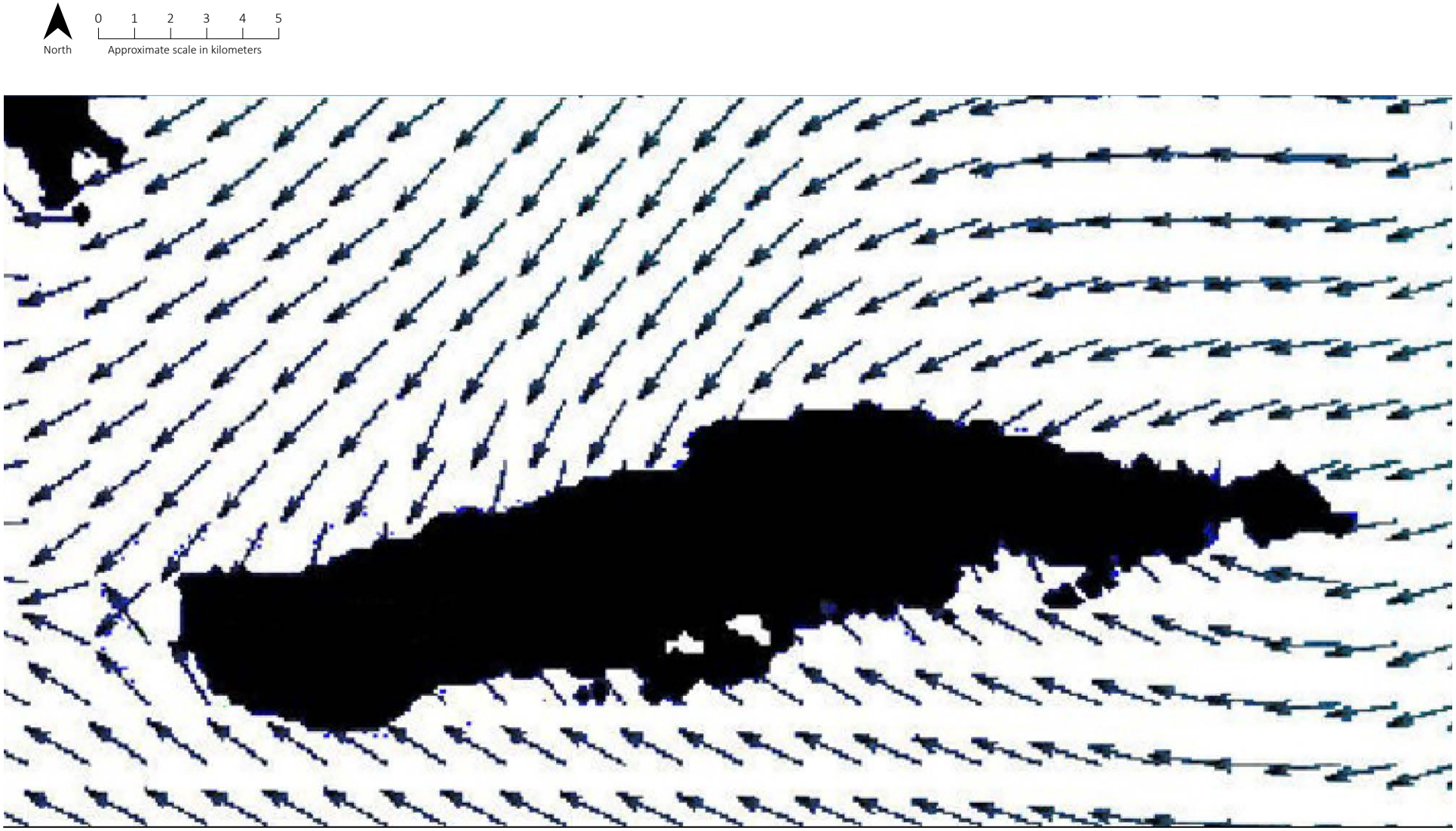
Aerial reference 2017 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image © 2017 CNES/Airbus.



NOTES:

1. Bathymetric contours represent meters from mean sea level.
2. ECA = Eastern Conservation Area.
3. EMA = Eastern Maneuver Area.
4. LIA = Live Impact Area.
5. MOV = Municipality of Vieques.
6. NASD = Naval Ammunition Support Detachment.
7. SIA = Surface Impact Area.
8. SWMU = Solid Waste Management Unit.

FIGURE 3-1
Bathymetry Around Vieques
Beach Dynamics Investigation Report
Vieques, Puerto Rico



NOTE: Wave data from CARICOOS, 2016.

FIGURE 3-2
Wave Refraction Pattern Around Vieques for Easterly Waves
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial reference 2017 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image 2017 Landsat/Copernicus. Image © 2017 Digital Globe. Image © 2017 CNES/Airbus.

FIGURE 3-3
Locations of NOAA Stations 9751639 Charlotte Amalie, 9752695 Esperanza, and 9752619 Isabel Segunda
Beach Dynamics Investigation Report
Vieques, Puerto Rico

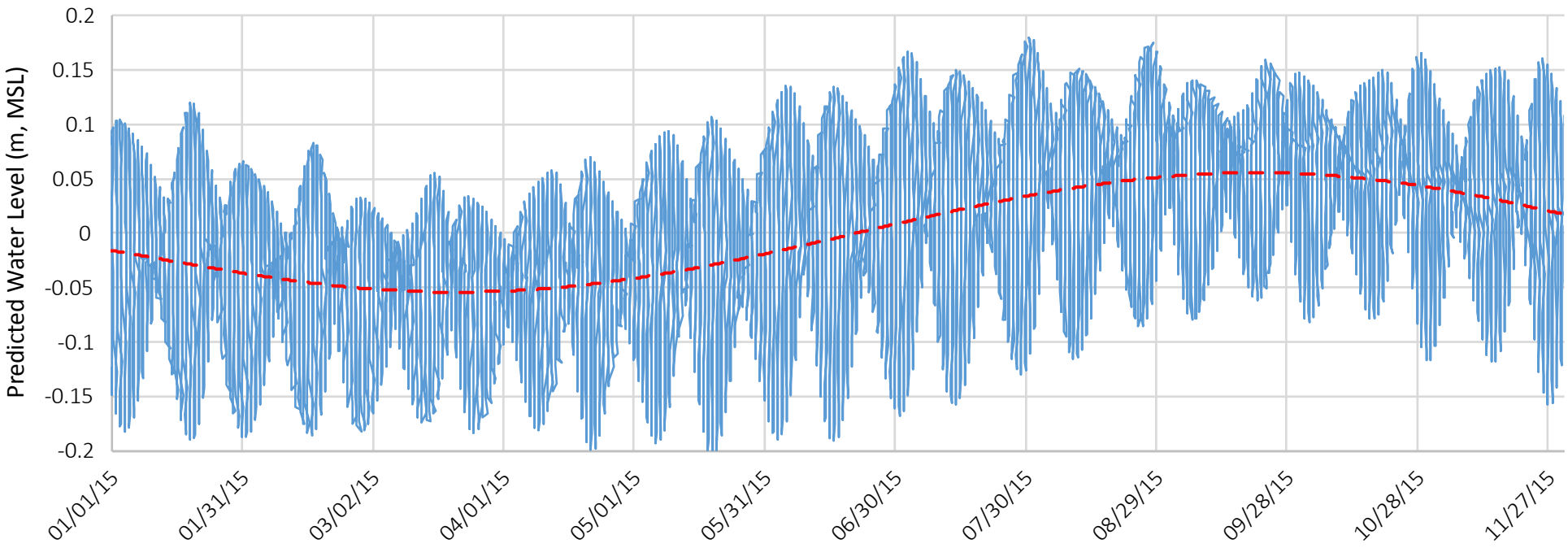


FIGURE 3-4
Time History of Water Levels Predicted at NOAA Station 9752695 Esperanza for 2015
Beach Dynamics Investigation Report
Vieques, Puerto Rico

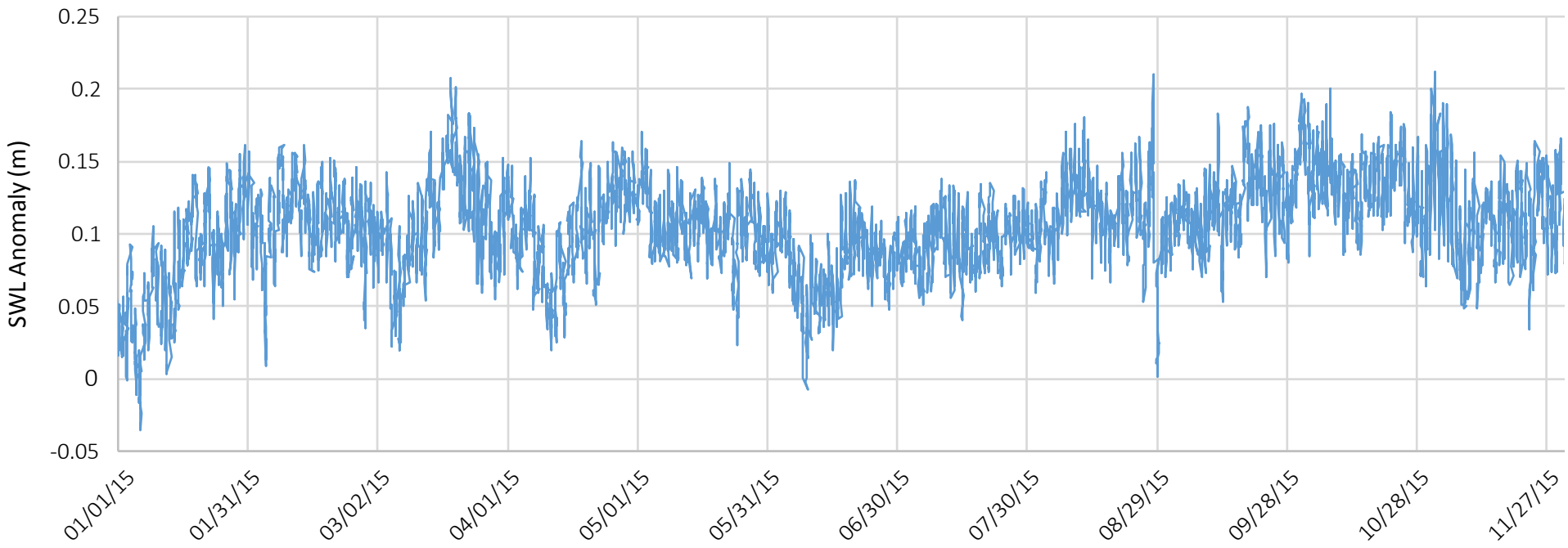
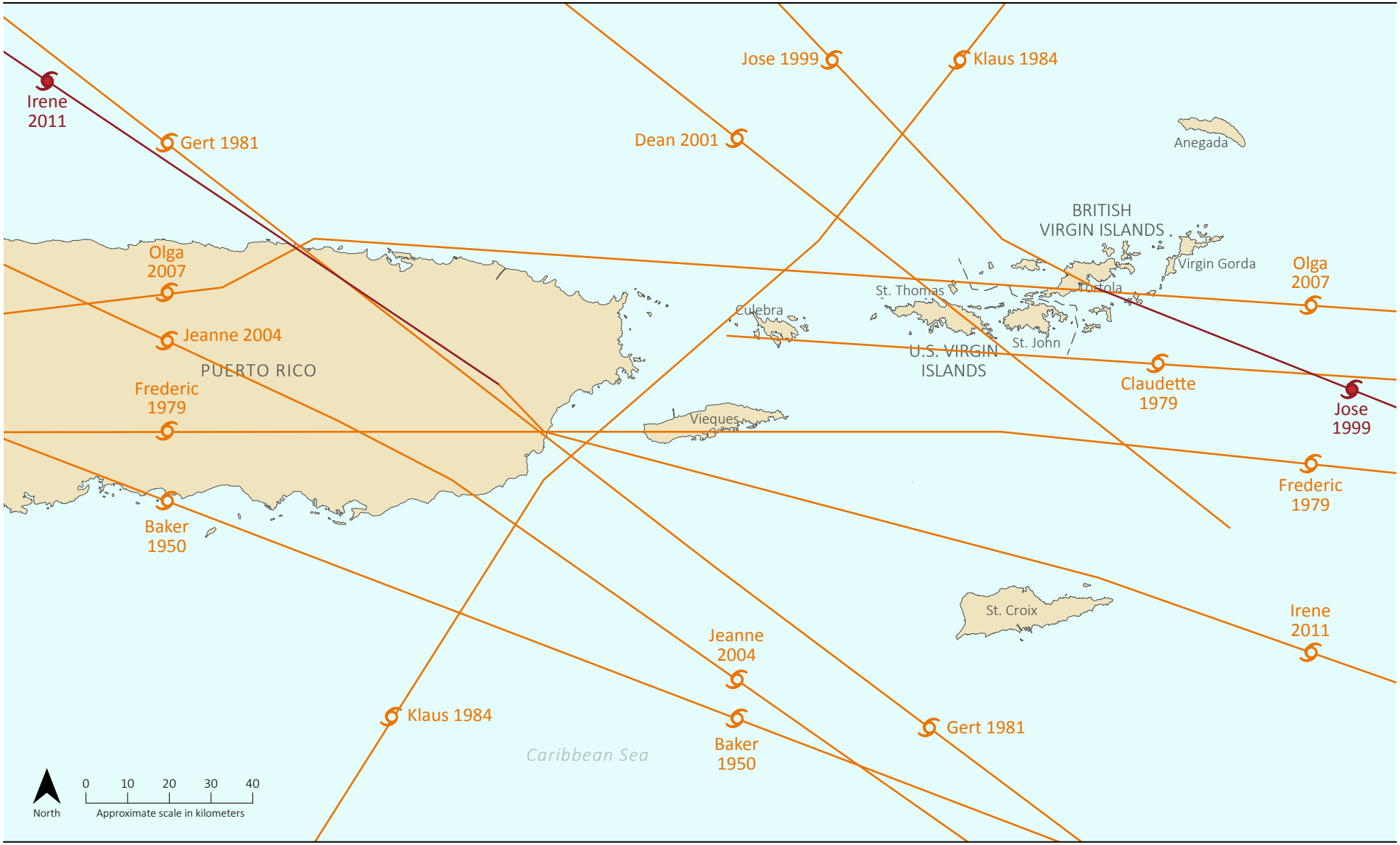


FIGURE 3-5
Still Water Level (SWL) Anomaly at
NOAA Station 9752695 Esperanza for 2015
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial reference 2017 Google Earth. Data LDEO-Columbia, NSF, NOAA. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image 2017 Landsat/Copernicus.



LEGEND

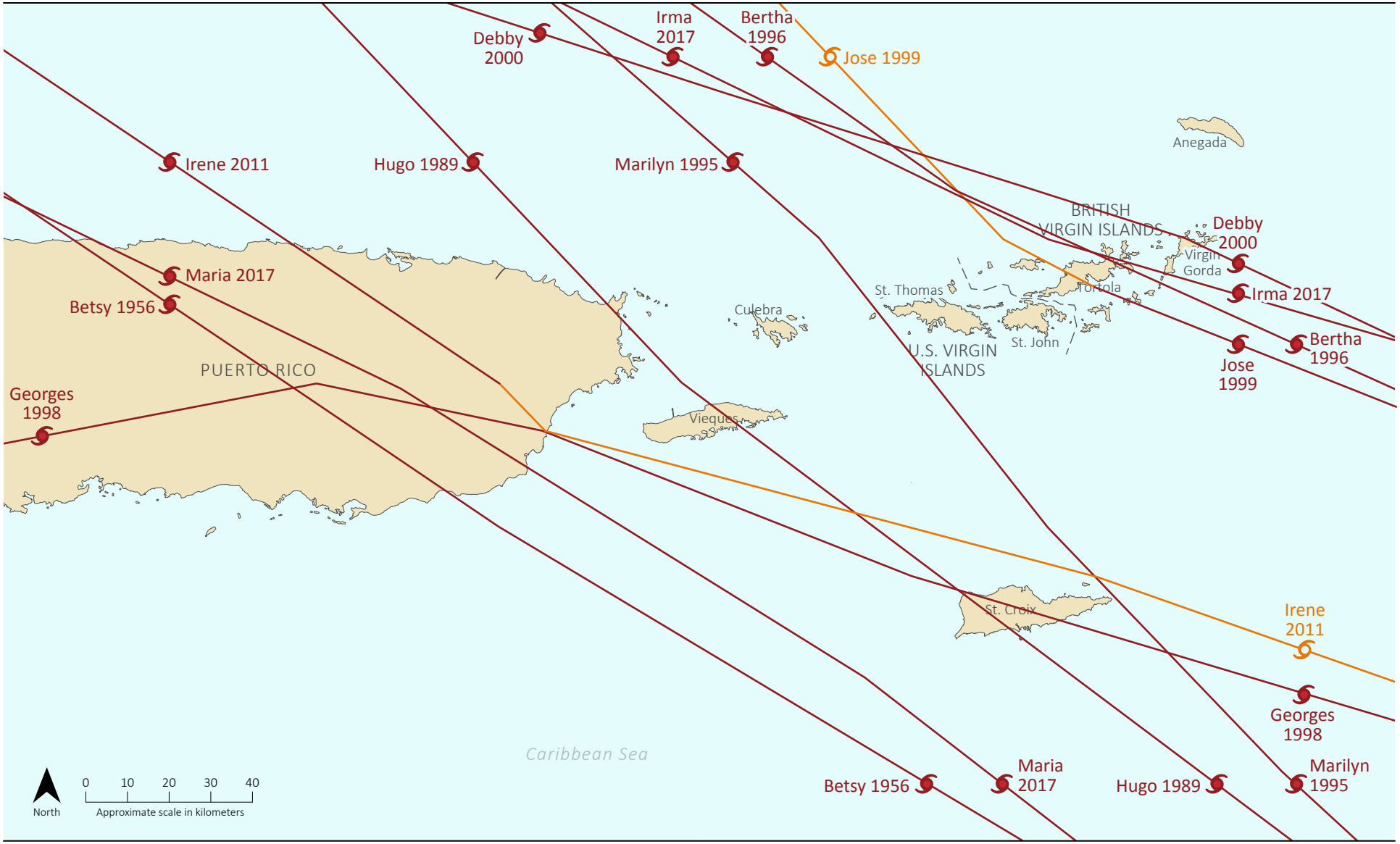
- Tropical storm track
- Tropical storm
- Hurricane track
- Hurricane

NOTE: nm = Nautical Mile.

FIGURE 3-6
Tracks of Historical Tropical Storms from 1950 to 2017 within 50-nm Radius from Vieques
Beach Dynamics Investigation Report
Vieques, Puerto Rico

NG0831170645VBO_r1

Aerial reference 2017 Google Earth. Data LDEO-Columbia, NSF, NOAA. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image 2017 Landsat/Copernicus.



LEGEND

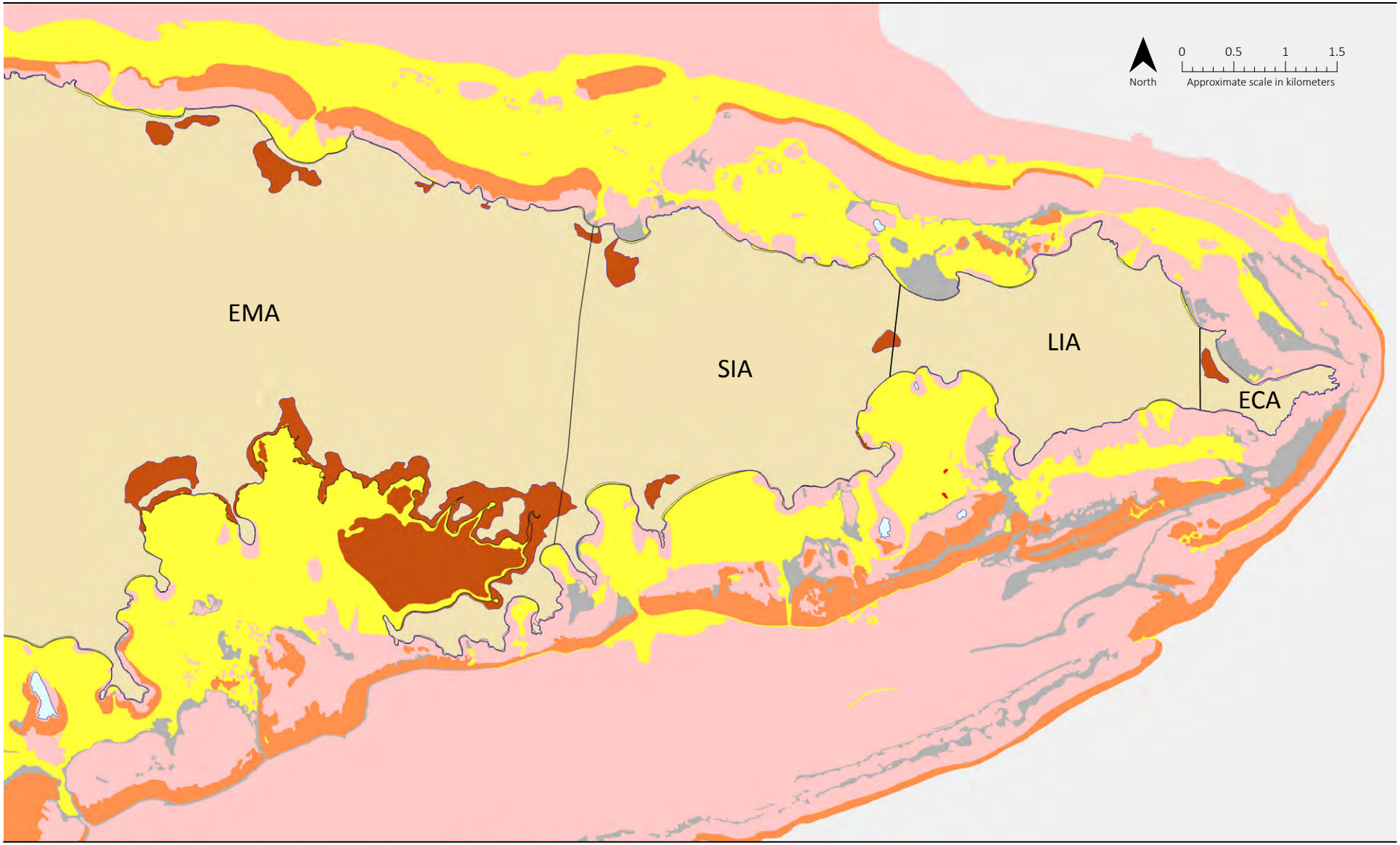
- Hurricane track
- Hurricane
- Tropical storm track
- Tropical storm

NOTE: nm = Nautical Mile.

FIGURE 3-7
Tracks of Historical Hurricanes from 1950 to 2017 within 50-nm Radius from Vieques
Beach Dynamics Investigation Report
Vieques, Puerto Rico

NG0831170645VBO_r1

Aerial reference 2017 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image © 2017 TerraMetrics. Image © 2017 CNES/Airbus.



LEGEND

- Coral reef, 0 to < 10 percent
- Coral reef, 10 to < 50 percent
- Mud
- Sand
- Sand with coral and rock

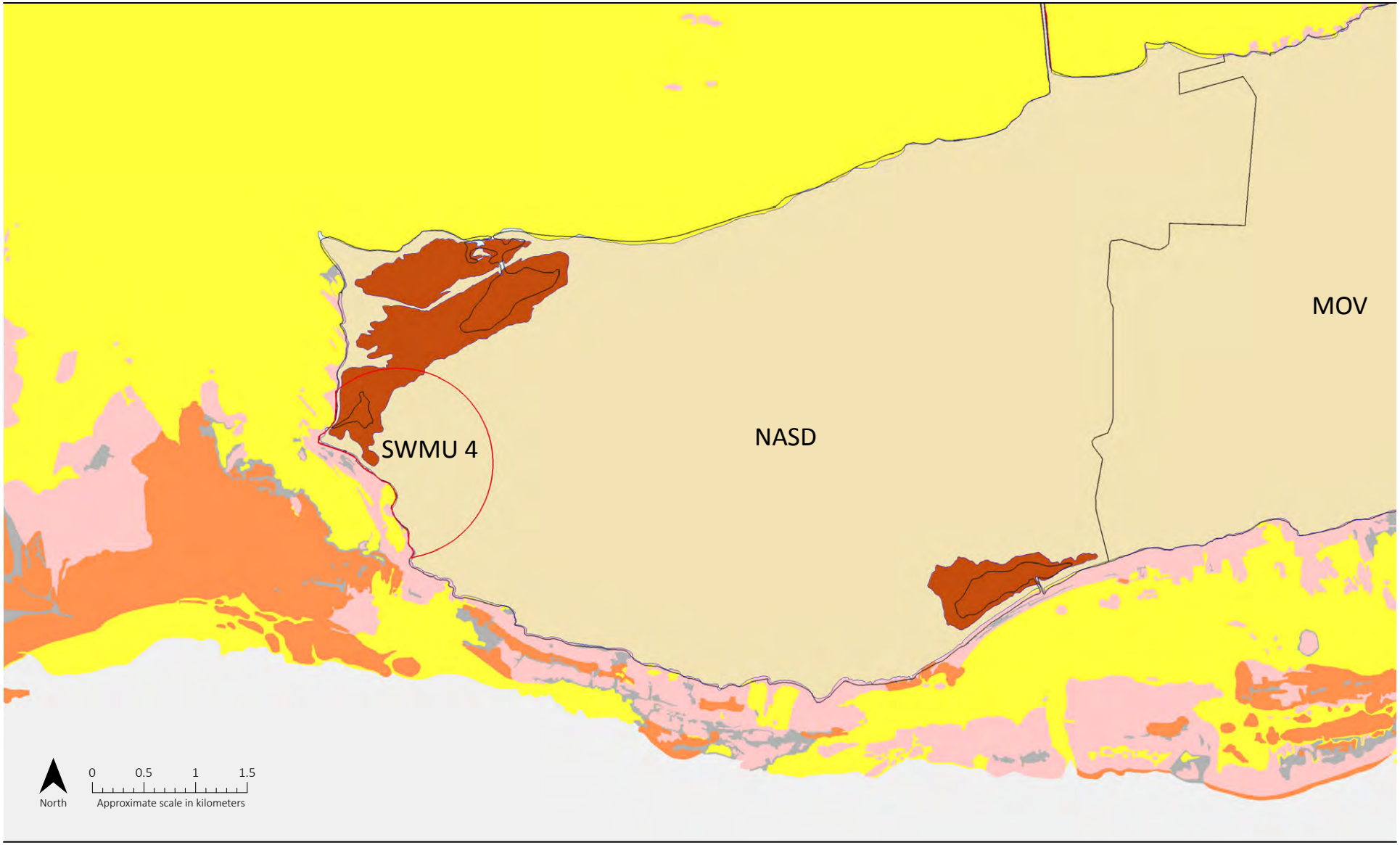
NOTES

1. ECA = Eastern Conservation Area.
2. EMA = Eastern Maneuver Area.
3. LIA = Live Impact Area.
4. SIA = Surface Impact Area.
5. VNTR = Vieques Naval Training Range.

FIGURE 3-8
Geomorphological Structures Around the Former VNTR
Beach Dynamics Investigation Report
Vieques, Puerto Rico

NG0831170645VBO

Aerial reference 2017 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image © 2017 Digital Globe. Image © 2017 CNES/Airbus.



LEGEND

- Coral reef, 0 to < 10 percent
- Coral reef, 10 to < 50 percent
- Mud
- Sand
- Sand with coral and rock

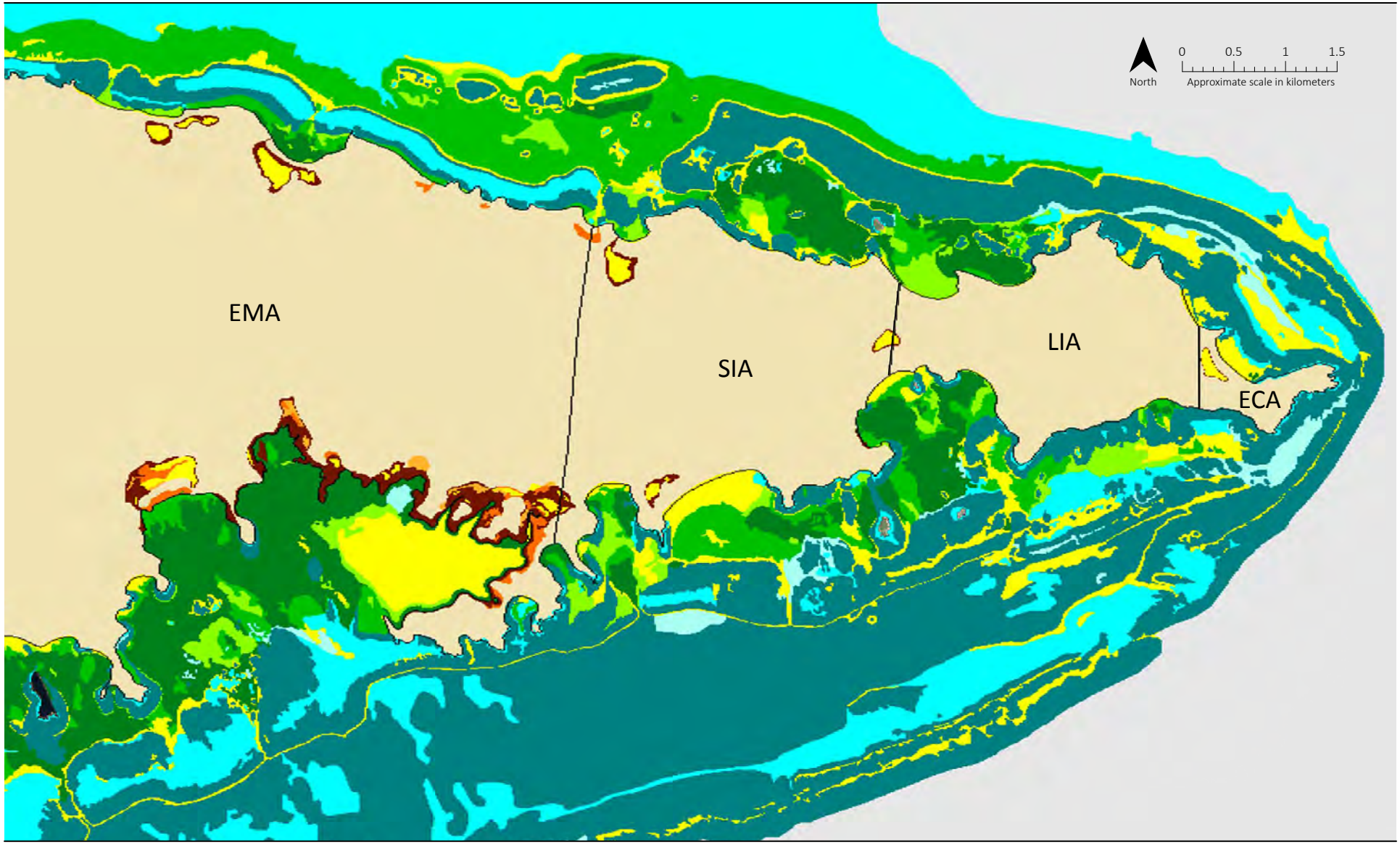
NOTES

1. MOV = Municipality of Vieques.
2. NASD = Naval Ammunition Support Detachment.
3. SWMU = Solid Waste Management Unit.

FIGURE 3-9
Geomorphological Structures Around the Former NASD
Beach Dynamics Investigation Report
Vieques, Puerto Rico

NG0831170645VBO

Aerial reference 2018 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image © 2018 TerraMetrics.



LEGEND

- Algae, 10 to < 50 percent
- Algae, 50 to < 90 percent
- Algae, 90 to 100 percent
- Mangrove, 10 to < 50 percent
- Mangrove, 50 to < 90 percent
- Mangrove, 90 to 100 percent
- Seagrass, 10 to < 50 percent
- Seagrass, 50 to < 90 percent
- Seagrass, 90 to 100 percent
- No cover

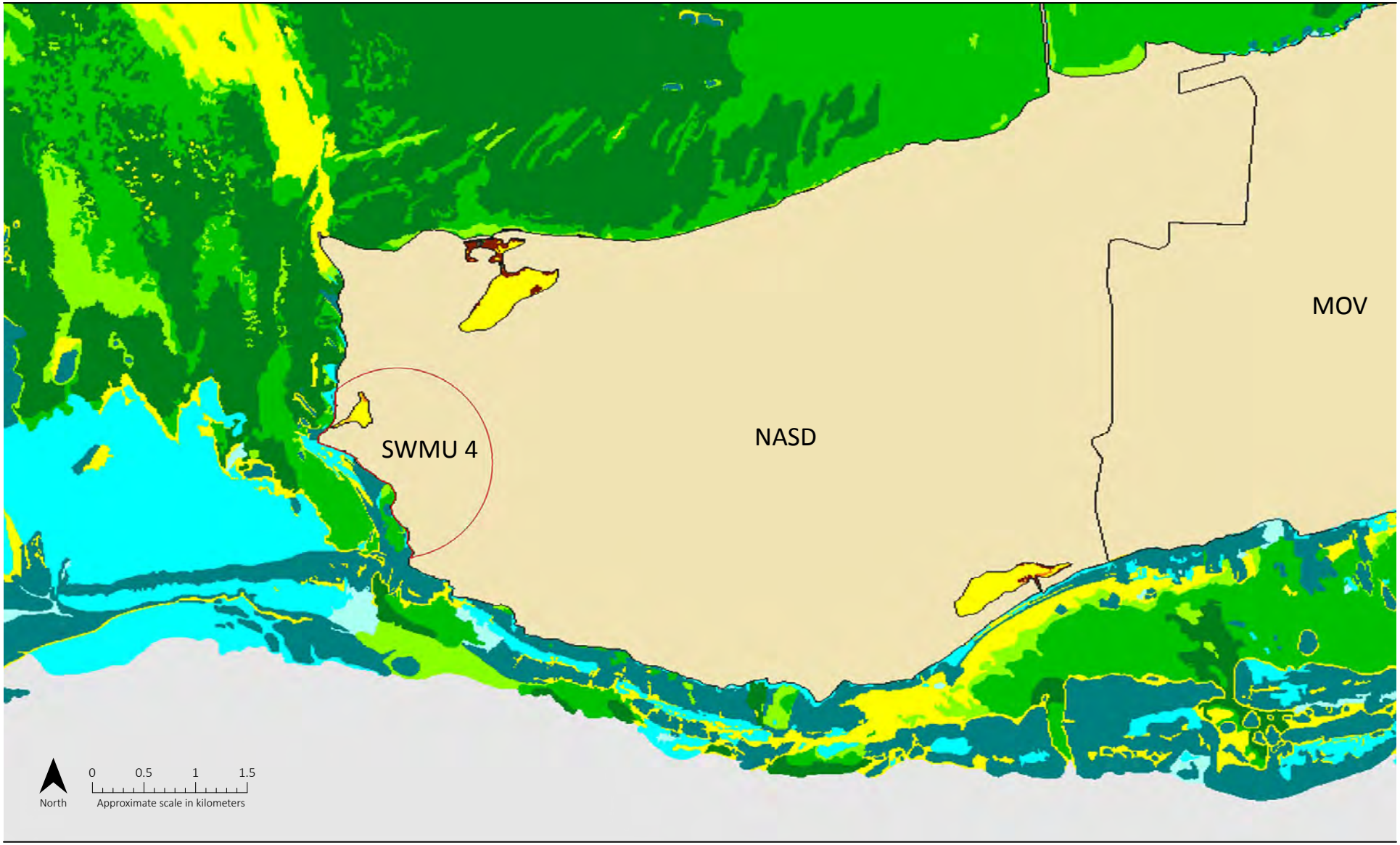
NOTES

1. ECA = Eastern Conservation Area.
2. EMA = Eastern Maneuver Area.
3. LIA = Live Impact Area.
4. SIA = Surface Impact Area.
5. VNTR = Vieques Naval Training Range.

FIGURE 3-10
Biological Cover Around the Former VNTR
Beach Dynamics Investigation Report
Vieques, Puerto Rico

NG0831170645VBO

Aerial reference 2018 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image © 2018 TerraMetrics.



LEGEND

- Algae, 10 to < 50 percent
- Algae, 50 to < 90 percent
- Algae, 90 to 100 percent
- Mangrove, 10 to < 50 percent
- Mangrove, 50 to < 90 percent
- Mangrove, 90 to 100 percent
- Seagrass, 10 to < 50 percent
- Seagrass, 50 to < 90 percent
- Seagrass, 90 to 100 percent
- No cover

NOTES

1. MOV = Municipality of Vieques.
2. NASD = Naval Ammunition Support Detachment.
3. SWMU = Solid Waste Management Unit.

FIGURE 3-11
Biological Cover Around the Former NASD
Beach Dynamics Investigation Report
Vieques, Puerto Rico

NG0831170645VBO

SECTION 4

Summary of Field Activities

To best plan the BDI activities, a reconnaissance site visit was performed between March 11 and 15, 2013 (CH2M, 2014). The site visit included a visual assessment of the 11 beaches selected for the BDI. The inspections were documented with photos and field notes that were used for reference, planning of the BDI, and in the analysis of results.

The assessment of the characteristics and condition of the beaches included an inventory of coastal features; proximity of creeks, lagoons, and wetlands; verification of coastal features in aerial photos; evaluation of general beach sediment characteristics; identification of potentially significant erosion/accretion areas and high-water level marks; and wave conditions and predominant sediment transport at each beach selected for the BDI.

During the site visit, potential locations for survey control benchmarks, sediment samples, waves, currents, and water levels were evaluated, the approach to the beach surveys considered, and backshore features were examined so that landward limits for the planned BDI surveys could be determined.

This section provides the details of the BDI general approach listed in Section 1.2. Field activities were conducted in general accordance with the BDI QAPP (CH2M, 2014); any deviations are discussed in the subsections below. All activities were conducted using unexploded ordnance (UXO) personnel support.

4.1 Wave Measurements

The offshore wave climate in Vieques is predominantly from the east during most of the year and from the northeast during the winter. Because most of the beaches selected for the BDI are located along the north, south and east coasts of the former VNTR there was no one offshore location that would suffice to characterize the wave climate for the entire area under study. Therefore, waves were measured at three locations in the offshore vicinity of Vieques. Other considerations for the selection of the measurement locations included distance to the coast, since being too close to the coast may produce measurements biased due to the transformation of waves by local coastal features, or measurements too far from the coast may not adequately represent the wave climate, in addition to encountering water depths that could have potentially complicated the deployment and maintenance of the sensors. Consequently, the three locations were selected based on inspection of wave refraction patterns modelled by Caribbean Coastal Ocean Observing System (CARICOOS) and available at their website, and deployment logistics. Conditions at the selected locations included water depths in the range of 13 to 17 m, sandy and flat leveled bottom away from steep bottom slopes, reefs, rock outcroppings.

Waves were measured with acoustic wave and current (AWAC) sensors acquired from NortekUSA, from October 2014 to December 2016. For identification purposes, the AWACs were named according to their location: AWAC-N(orth) was deployed on the north coast just offshore and to the northeast of Beach 22 in a water depth of approximately 16.5 m PRVD02, AWAC-E(ast) at the east end of Vieques just offshore Beaches 12 and 14 in 12.8 m PRVD02, and AWAC-S(outh) on the south coast to the southeast of Beaches 2, 3 and 4 in 17.5 m PRVD02. **Figure 4-1** shows the AWACs locations, and the beaches selected for the BDI at the former VNTR.

Additional information about the sensors, setup, deployment, and maintenance is included in **Appendix A**.

4.2 Water Level Measurements

Water levels at NOAA Stations 9752695 Esperanza and 9752619 Isabel Segunda in Vieques were the main sources of water level data during the BDI; the data were downloaded from NOAA's website. **Figure 4-2** shows the location of these stations.

- NOAA Station 9752695 Esperanza, PR
  https://tidesandcurrents.noaa.gov/stationhome.html?id=9752695

- NOAA Station 9752619 Isabel Segunda, PR
  https://tidesandcurrents.noaa.gov/stationhome.html?id=9752619

4.3 Rainfall Measurements

Rainfall was measured with a gauge at Camp Garcia from the end of March 2015, to the end of December 2016. Manufactured by Hydrological Services Pty Ltd., the TB4 rainfall gauge was installed on the roof of the former galley. This location was selected based on quick access for data download and ease of maintenance. **Figure 4-3** shows the location of the rainfall gauge. Additional information about the rainfall measurements and the rainfall gauge can be found in **Appendix B**.

4.4 Beach Surveys

4.4.1 Beach Selection

The BDI included the survey of the following 10 beaches at the former VNTR and 1 beach at the former NASD, shown in **Figure 4-4**:

- LIA Beaches, UXO 2
  - Beach 2 (Unnamed)
  - Beach 3 (Playa Salina del Sur)
  - Beach 4 (Turtle Beach/Playa Carrucho)
  - Beach 5 (Icacos/Playa Yallis)
  - Beach 12 (Unnamed)
  - Beach 14 (Playa Brava)
- North EMA and SIA Beaches, UXO 7
  - Beach 22 (Puerto Diablo)
  - Beach 24 (Purple Beach/Playa Campaña)
- South SIA Beaches, UXO 8
  - Beach 1 (Yellow Beach/Playa Matías)
  - Beach 19 (Playa Yoyé)
- SWMU 4
  - Unnamed Beach

These beaches were selected based on a variety of reasons, including:

- Representative of dynamic behavior due to:
  - Wave exposure (Beaches 1 and 2 on exposed south coast; Beaches 3, 4 and 19 on protected south coast; Beaches 12 and 14 on exposed east coast; Beach 5 on protected north coast; Beaches 22 and 24 on exposed north coast; and SWMU 4 on exposed west coast)
  - Nearshore bathymetry (Beaches 1, 2, 3, 4 and 19 on south coast; Beaches 12 and 14 on east coast; Beaches 5, 22 and 24 on north coast; and SWMU 4 on west coast)
- Quantity/type of MEC previously encountered (Beaches 1, 2, 3, 4, 5, 12, 14, 19, 22 and 24)
- Potential future public use (Beaches 19, 24, and SWMU 4)
- Popular beaches for trespassers (Beaches 2, 3, 4, 5, 22, 24 and SWMU 4)

- Ecological significance (e.g., turtle nesting) (Beaches 1, 2, 3, 4, 5, 12, 14, 22, 24 and SWMU 4)

The selected beaches are representative of the remainder of the beaches in the former VNTR and NASD, as they include the broad range of characteristics found across Vieques. While MEC may be present at beaches not selected for the BDI, the information from those selected can be used to help make decisions for those not selected.

Based on observations made during the BDI, **Table 4-1** summarizes some of the principal characteristics of the beaches and behavior given their orientation, wave exposure and general site conditions.

4.4.2 Survey Approach and Methodology

The approach selected to evaluate the dynamic behavior of the beaches consisted of performing monthly surveys of beach and sea bottom profiles (beach surveys) along shoreline-perpendicular transects extending from the backshore to the nearshore, comparing the corresponding profiles, and analyzing their evolution through time. In the first year of surveying, from April 2015 to March 2016, monthly beach surveys were performed at all 11 beaches. Once the surveying scope of work defined in the BDI QAPP (CH2M, 2014) was completed, monthly surveying continued, from April 2016 to December 2016 at 5 beaches at the former VNTR (Beach 1, 2, 12, 14 and 24). Results of the 12 months of the BDI (i.e., the duration in the QAPP) showed that Beaches 3, 4, 5, 19 and 22 were stable, with profiles and shorelines exhibiting minimal changes.

For each beach, the transect locations were selected based on representativeness of beach characteristics, coastal processes, nearshore bathymetry, and coastal morphology, and with the objective of capturing the spatial variability that the beaches could experience in longshore and cross-shore directions. Beach characteristics were assessed during the site visit of March 2013, which included observations and measurements of beach slope and the determination of potential erosion or accretion areas. These were analyzed, in conjunction with aerial photographs, nearshore bathymetry, coastal morphology, habitats, and estimates of wave conditions to define, in a qualitative manner, the extent of potential beach changes. The analyses yielded transect layouts intended to capture the spatial variability of the beach changes. For each beach, transects were arranged along the beach approximately equally spaced and perpendicular to the shoreline from a backshore boundary extending to the nearshore, covering and bracketing the beach and sea bottom areas expected to change. The survey frequency and duration was designed to capture the seasonal, as well as more frequent, variability of the beaches.

Beach profiles were measured using a combination of Real Time Kinematics (RTK) Global Positioning System (GPS) and a survey boat-based single-beam depth sounder along the selected transects. To ensure accurate surveys, a benchmark network was set up and used for checking the GPS receivers before the surveys. For every survey, land and boat crews met to discuss the survey plan for the day and inspect survey equipment. Following the meeting, the land crew set up the RTK GPS equipment and checked its performance against a benchmark. At each beach to be surveyed, the land crew checked the performance of the survey equipment against a benchmark. Each transect was surveyed by the land crew by foot covering the backshore and then the shoreline section to approximately waist depth. The boat crew surveyed all transects from the transects' toes (the seaward end of the transect) to as close to the shore as possible to ensure overlap with the land-based surveys.

The coordinate system adopted for the BDI and information about the benchmark network setup is included in **Appendix C**.

Information about the beach surveys, including descriptions of beaches, locations of beach transects, equipment and personnel used, procedure, quality control and survey dates, is provided in **Appendix D**.

4.5 Sediment Sampling and Analysis

Sediment characteristics control the response of beaches, and the interaction between objects such as MEC and the sea bottom, and the bottom with wave and current induced flows. Therefore, the characterization of sediments in terms of grain size, sorting, and cross-shore distribution is important for the analysis of beach response, determination of beach slopes, and for the prediction of sediment transport, and burial and mobility of

MEC. Additionally, grain size data can be used to compute theoretical beach profiles, in sediment transport models, and to calibrate/verify models to estimate long term (e.g., years or decades) beach evolution.

To characterize the sediments, grab samples of the top 5 to 10 cm of beach sediment and nearshore bottom were collected approximately quarterly for the first year at each of the 11 beaches selected for the BDI. The samples were collected along one selected transect at each beach, and at backshore, shoreline, and nearshore locations. Transects and number, sampling frequency and location of samples were selected to represent, to the extent practical, beach-wide and seasonal conditions. Samples were collected during the beach surveys as follows:

1. April/May 2015
2. August 2015
3. November 2015
4. February 2016

Sample locations, sampling procedures, and data analysis are described in **Appendix E**.

4.6 MEC Surrogate Surveys

As a result of beach accretion, previously buried MEC could be buried even deeper making it undetectable, and because of beach erosion previously buried MEC could become exposed and/or detectable, and even transported by waves and currents. In addition, the hydrodynamic forces induced by waves and currents could intermittently bury, expose and transport MEC and other metallic debris present in beaches and nearshore areas. The combination of these processes makes the burial and mobility of MEC complex to assess and predict, at Vieques, where little was known about these processes.

To augment the current understanding of the impact of the dynamic behavior of the beaches and metocean conditions in Vieques on the burial and mobility of MEC, surrogates were deployed at nine beaches, and their locations were surveyed (tracked) approximately monthly concurrently with the beach surveys. Sixty-one surrogates of representative MEC likely to be found in the former VNTR nearshore environment were fabricated, replicating shape and mass properties, and deployed at 9 beaches of the former VNTR. The surrogates were characterized by color, identification labels, and equipped with acoustic transmitters for identification and localization. Surrogates were located and identified from the survey boat by their acoustic signature, with subsequent visual confirmation, and position surveyed with RTK GPS.

Table 4-2 lists the MEC types selected for surrogate tracking during the BDI and their nominal characteristics. The surrogates were deployed between March 25 and April 1, 2015 and distributed according to **Table 4-3**. No surrogates were deployed at Beach 12 because surrogates deployed at nearby Beach 14 were expected to behave similarly. No surrogates were deployed at SWMU 4 because surveys at that beach and in the adjacent offshore area suggest no significant presence of munitions.

Figure 4-5 shows the deployment locations of the surrogates, and their distribution per type and beach. Surrogates at the same locations were deployed a few meters apart from each other to minimize interference.

Appendix F describes the fabrication of the surrogates and quantities, and includes deployment locations and methodology; survey equipment, procedure, and dates; maintenance; diver surveys; and surrogate recovery.

4.7 Metocean Field Observations

During the monthly beach and MEC surrogate surveys and at every beach, the crews performed visual observations and developed estimates of wind, wave, and general beach conditions. These estimates were approximate and intended to gain a preliminary knowledge of the conditions at the beaches, including seasonality, to help verify estimates made by others, and for qualitative reasonableness checks.

The boat crew assessed wave height by visual estimation, wave period by timing and counting waves within a defined interval, wind and wave direction by heading the survey boat into the respective directions and using a

magnetic compass, and wind speed by its observable effects on water and land features. The land crew assessed wave breaking height by visual estimation, wave period by timing and counting waves within a defined interval, wind direction using a magnetic compass, and wind speed by its observable effects on water and land features.

Observed wind, wave and general beach conditions were entered in a spreadsheet and database for review and analysis.

Appendix G includes the graphs with the observations made by the crews.

4.8 Third-party Metocean Data Collection

Third-party metocean data were collected to characterize local and regional metocean conditions and to support potential future studies, if warranted. Sources included online repositories from NOAA, the National Data Buoy Center (NDBC) and CARICOOS. NOAA operates coastal metocean stations that measure water levels; wind speed, direction, and gust; atmospheric pressure; and air and water temperature. NDBC and CARICOOS operate buoys that measure wind direction, speed, and gust; wave height, period, and direction; and atmospheric pressure.

Figure 4-6 shows the locations of the stations within 40 nm from Vieques. Because of their distance, NDBC buoys located between 200 and 500 nm from Vieques: 41043 (NE Puerto Rico), 41044 (NE St. Martin), 42059 (Easter Caribbean Sea) and 42060 (Caribbean Valley) are not shown on the figure so that the locations of the other buoys is easier to discern.

Appendix H list of the sources of metocean data and links to online station information and data.

TABLE 4-1
Summary of Principal Characteristics of BDI Beaches
Beach Dynamics Investigation Report
Vieques, Puerto Rico

UXO, Beach	Orientation [a]	Length	Wave Exposure	Dynamics
UXO 2, Beach 2 - Unnamed	southeast	600 m	exposed	dynamic
UXO 2, Beach 3 - Playa Salina del Sur	southeast	150 m	protected	stable
UXO 2, Beach 4 - Turtle Beach/Playa Carrucho	southwest	500 m	protected	stable
UXO 2, Beach 5 - Icacos/Playa Yallis	northeast	1,100 m	protected	stable
UXO 2, Beach 12 - Unnamed	northeast	300 m	exposed	dynamic
UXO 2, Beach 14 - Playa Brava	northeast	400 m	exposed	dynamic
UXO 7, Beach 22 - Puerto Diablo	north	500 and 300 m	exposed	dynamic
UXO 7, Beach 24 - Purple Beach/Playa Campaña	north	1,100 m	exposed	dynamic
UXO 8, Beach 1 - Yellow Beach/Playa Matías	southeast	1,000 m	exposed	dynamic
UXO 8, Beach 19 - Playa Yoyé	southeast	300 m	protected	stable
SWMU 4 - Unnamed	southwest and west	950 and 500 m	exposed	stable

a. facing
m = meter
Length - distance from one end to the other of the beach along the shoreline
Wave Exposure - classifies the beach based on its exposure or not to waves
Dynamics - classifies the beach based on its response to wave action

TABLE 4-2
MEC Surrogate Types and Nominal Characteristics
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Type	Weight	Length	Diameter		LCG
			Maximum	Location from Tip	
5-inch 38 Caliber Projectile	52	20	5	8.5	13
2.75-inch Rocket	15	55	2.75	3.5	20
MK 82 Bomb	530	88	11	20	37
MK 118 Submunition	2	13.5	2.2	2.6	6
81-mm Mortar	7	12	3	3	4
MK 76 Practice Bomb	23	23	4	6	6.5

Weights in pounds, dimensions in inches

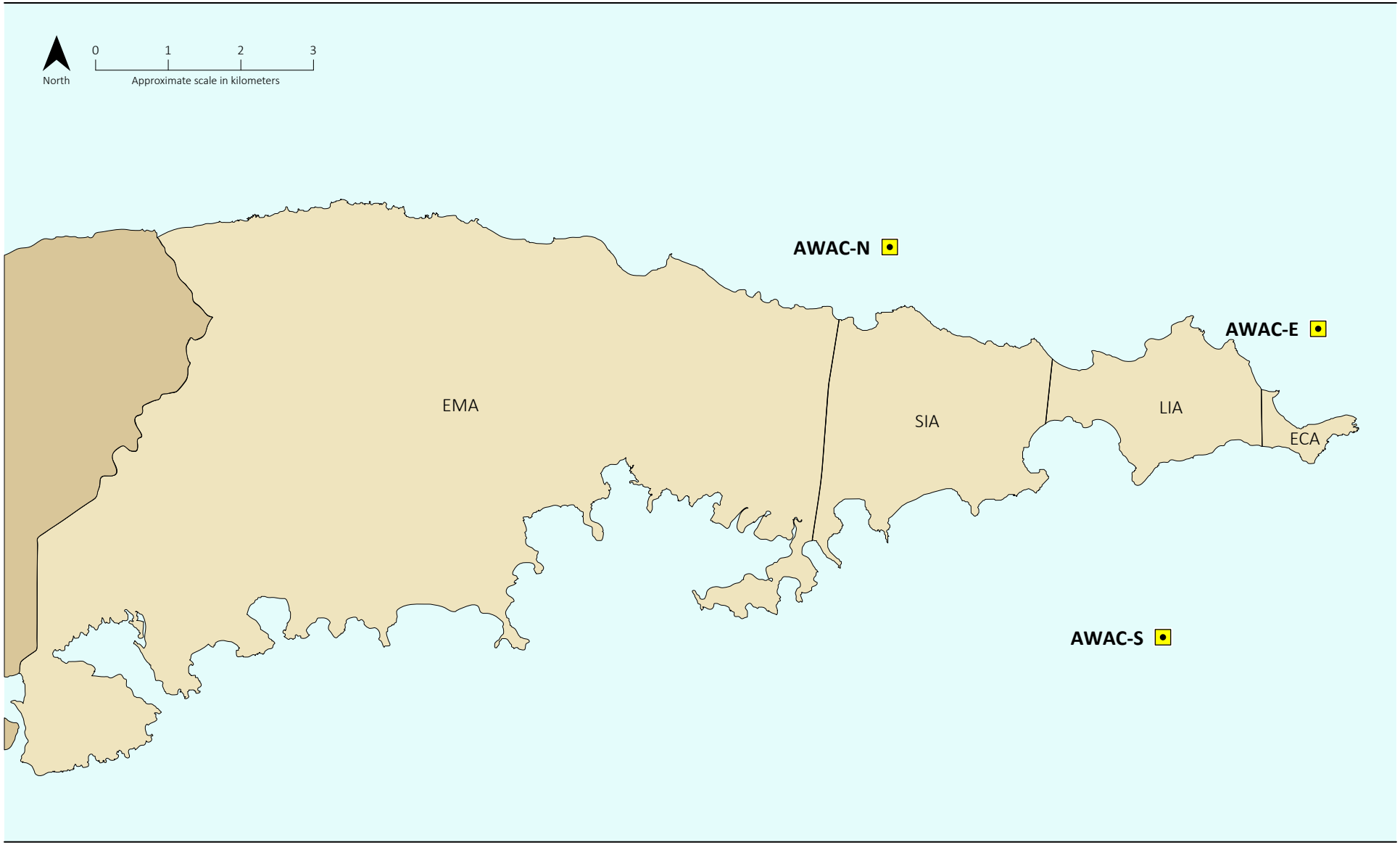
LCG is the longitudinal center of gravity from the tip of the surrogate
m = meter

TABLE 4-3
Quantities of MEC Surrogates per Beach
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Type	Beach								
	1	**2**	**3**	**4**	**5**	**14**	**19**	**22**	**24**
5-inch 38 Caliber Projectile		3	1	2	4	2	3		
2.75-inch Rocket		3	1	2	4	2			4
MK 82 Bomb		2	1	1	2	1			
MK 118 Submunition						2			
81-mm Mortar	4						3	5	
MK 76 Practice Bomb	4							5	

No surrogates were deployed at Beach 12 and SWMU 4.

Aerial reference image 2017 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image © 2017 CNES/Airbus. Image © 2017 DigitalGlobe.



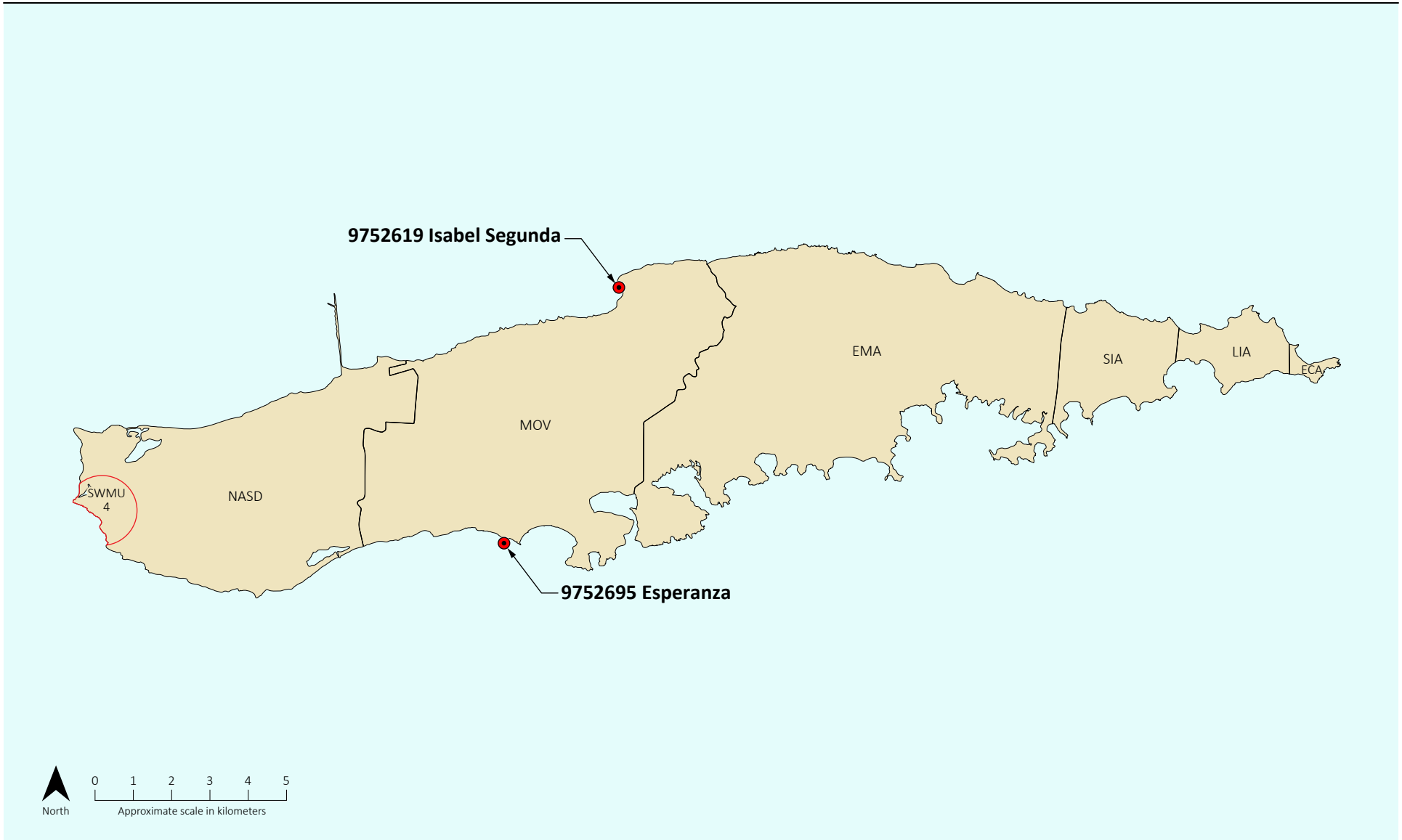
NOTES

1. AWAC = Acoustic Wave and Current.
2. ECA = Eastern Conservation Area.
3. EMA = Eastern Maneuver Area.
4. LIA = Live Impact Area.
5. SIA = Surface Impact Area.
6. VNTR = Vieques Naval Training Range.

FIGURE 4-1
AWAC Sensor Locations at the Former VNTR
Beach Dynamics Investigation Report
Vieques, Puerto Rico

NG0831170645VBO

Aerial reference image 2017 Google Earth. Image © 2017 CNES/Airbus. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image © 2017 DigitalGlobe.



NOTES:

1. ECA = Eastern Conservation Area.
2. EMA = Eastern Maneuver Area.
3. LIA = Live Impact Area.
4. MOV = Municipality of Vieques.
5. NASD = Naval Ammunition Support Detachment.
6. NOAA = National Oceanic and Atmospheric Administration.
7. SIA = Surface Impact Area.
8. SWMU = Solid Waste Management Unit.

FIGURE 4-2
Location of NOAA Water Level Stations 9752695 Esperanza and 9752619 Isabel Segunda
Beach Dynamics Investigation Report
Vieques, Puerto Rico

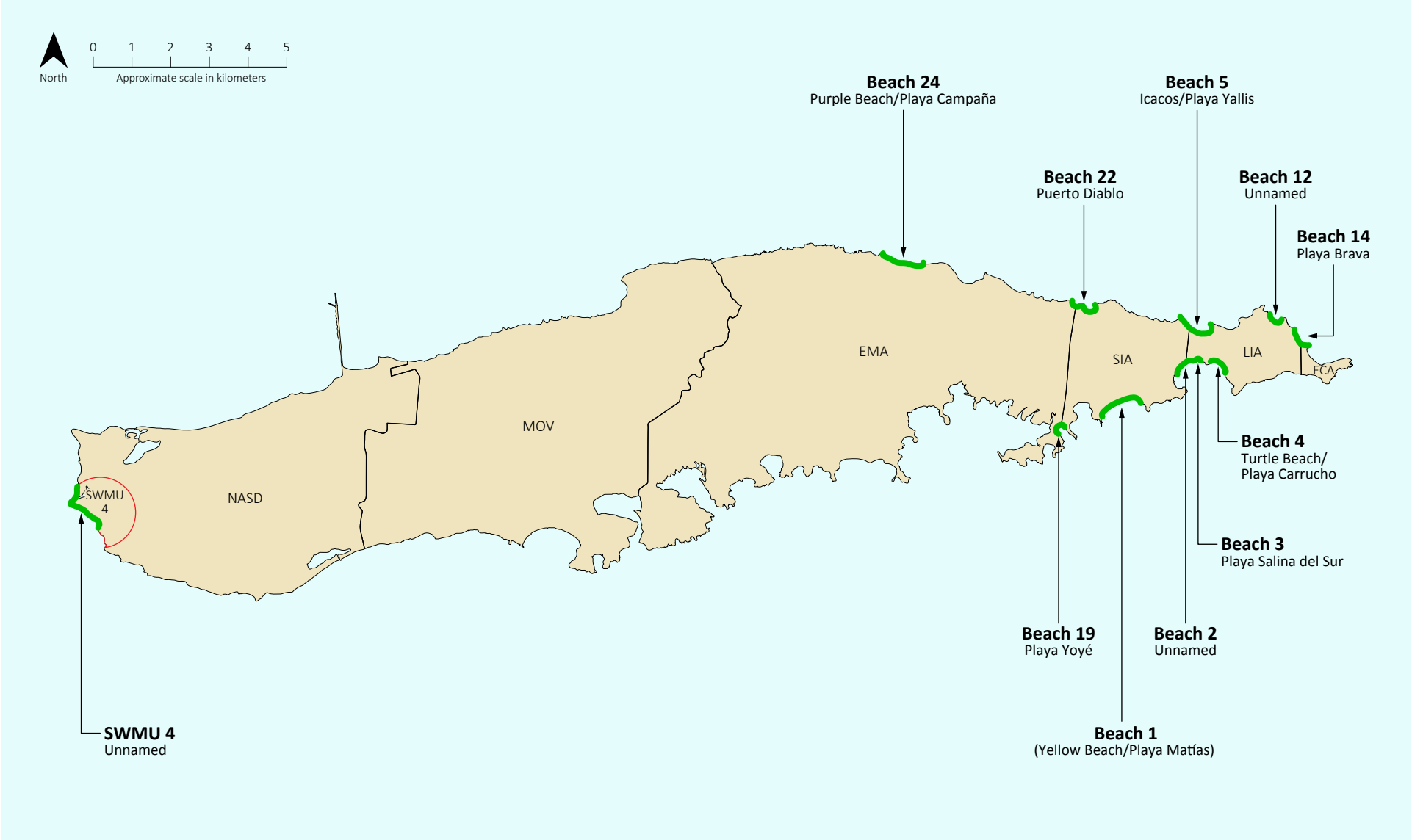
Aerial reference image 2017 Google Earth. Image © 2017 CNES/Airbus. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image © 2017 DigitalGlobe.

NOTES:

1. ECA = Eastern Conservation Area.
2. EMA = Eastern Maneuver Area.
3. LIA = Live Impact Area.
4. MOV = Municipality of Vieques.
5. NASD = Naval Ammunition Support Detachment.
6. SIA = Surface Impact Area.
7. SWMU = Solid Waste Management Unit.

FIGURE 4-3
Location of Rainfall Gauge
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial reference image 2017 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image © 2017 CNES/Airbus. Image © 2017 DigitalGlobe.

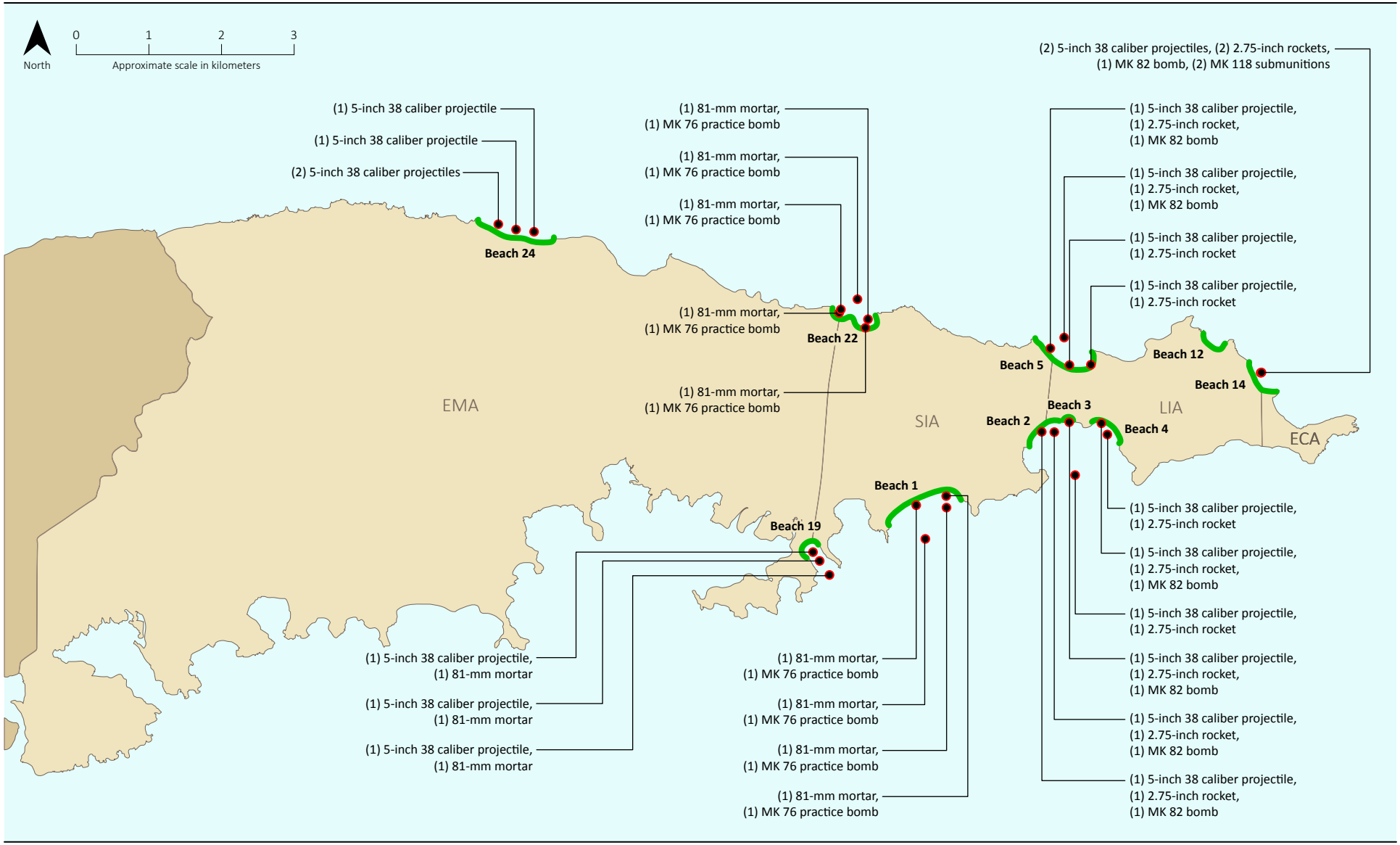


NOTES:

1. ECA = Eastern Conservation Area.
2. EMA = Eastern Maneuver Area.
3. LIA = Live Impact Area.
4. MOV = Municipality of Vieques.
5. NASD = Naval Ammunition Support Detachment.
6. SIA = Surface Impact Area.
7. SWMU = Solid Waste Management Unit.

FIGURE 4-4
Beaches Selected for the BDI
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial reference 2017 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image © 2017 CNES/Airbus. Image © 2017 DigitalGlobe.



LEGEND

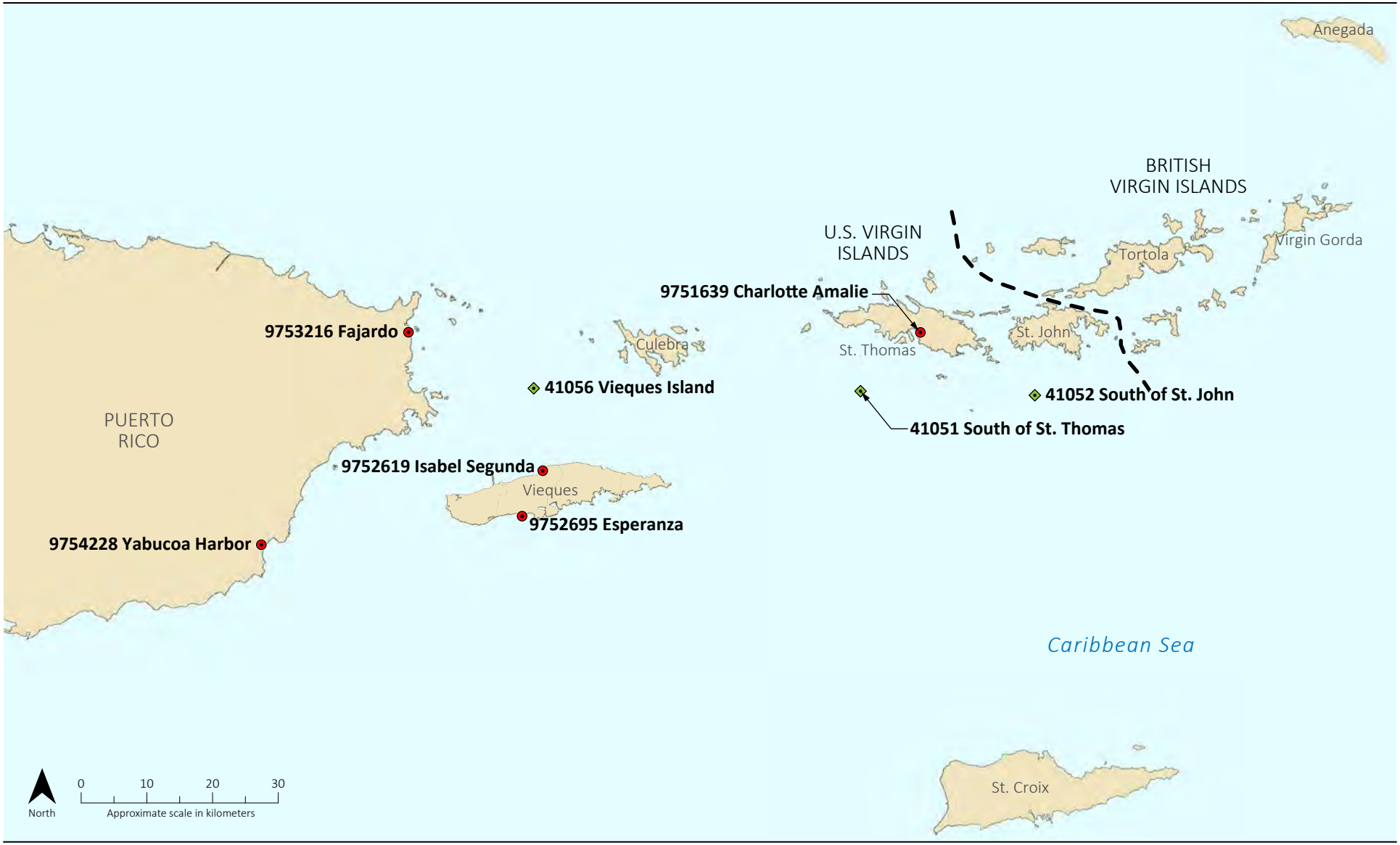
- Beach selected for investigation at former VNTR
- MEC surrogate deployment location (see Table 4-3 for quantities and types of surrogates deployed per beach, and Appendix F for location details)

NOTES

1. ECA = Eastern Conservation Area.
2. EMA = Eastern Maneuver Area.
3. LIA = Live Impact Area.
4. MEC = Munitions and Explosives of Concern.
5. SIA = Surface Impact Area.
6. VNTR = Vieques Naval Training Range.

FIGURE 4-5
Deployment Locations of MEC Surrogates at the Former VNTR
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial reference image 2017 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image 2017 Landsat/Copernicus.



LEGEND

- NOAA Coastal Metocean Station
- NDBC Wave Buoy

NOTES

1. NDBC = National Data Buoy Center.
2. nm = Nautical Mile.
3. NOAA = National Oceanic and Atmospheric Administration.

FIGURE 4-6
Locations of Third-party Metocean Data Collection Stations within 40 nm from Vieques
Beach Dynamics Investigation Report
Vieques, Puerto Rico

SECTION 5

Results and Analysis

The wave climate, storms, water levels and rainfall through surface water runoff, all drive beach changes and MEC burial and mobility in Vieques. These were characterized based on the measurements and analyses performed during the BDI, and their impacts on beach changes and MEC burial and mobility were assessed. The following sections summarize results and analyses.

5.1 Wave Climate

The wave climate during the BDI was characterized at the three locations where waves were measured. Results of the wave climate analysis are summarized below and detailed in **Appendix I**.

5.1.1 North Coast

At AWAC-N, and anywhere on along the north coast of Vieques where the bathymetry is similar, the local bathymetry would have a significant effect refracting incoming waves which are typically from the east, and from the northeast in the fall and winter. Typical significant wave heights at AWAC-N in spring and summer were in the order of 0.25 to 0.75 m, and increased in the fall and winter to 0.5 to 1 m. Typical peak wave periods ranged between 4 and 6 seconds, and increased in the fall and winter to 8 to 12 seconds, likely due to the incidence of northeast swell generated by North Atlantic Ocean storms, which are typical in those seasons. The mean wave direction was predominant from the northeast, due to the refraction effect caused by the local bathymetry, and to a lesser extent from the east regardless of the season. Waves from the north were rare and occurred mainly in the fall and winter.

5.1.2 East Coast

At AWAC-E, the local bathymetry does transform waves significantly because of the relative deep water, and because the depth contours are nearly perpendicular to the typical wave direction from the east and northeast. Therefore, the wave measurements at this location can be considered representative of the wave conditions offshore Vieques. Typical significant wave heights at AWAC-E were in the order of 0.75 to 1.25 m, and increased in the fall and winter to 1.25 to 1.75 m. Typical peak wave periods ranged between 4 and 6 seconds suggesting the incidence of locally generated wind waves, and increased in the fall and winter to 8 to 12 seconds, likely due to the incidence of swell generated by North Atlantic Ocean storms, which are typical in those seasons. The mean wave direction was predominant from the east, and to a lesser extent from the northeast in the fall and winter, and from the southeast in the spring and summer.

5.1.3 South Coast

At AWAC-S, and anywhere on along the south coast of Vieques where the bathymetry is similar, the local bathymetry would have a significant effect refracting incoming waves which are typically from the east. Typical significant wave heights at AWAC-S varied in the range of 0.50 to 1.25 m. Typical peak wave periods ranged between 4 and 8 seconds, independently of the seasons. The mean wave direction was predominant from the southeast due to the refraction effect caused by the local bathymetry, and to a lesser extent from the east regardless of the season. Waves from the south were rare.

5.1.4 Typicality Analysis

For the objectives of the BDI, it was important to qualify the typicality of the beach changes and MEC surrogate burial and mobility observed during the BDI. Because beach changes and MEC burial and mobility in Vieques are mainly driven by waves and wave-induced currents, the typicality of these would be related to the typicality of the wave climate present during the BDI. An analysis of wave climate typicality requires long-term measurements and among the various wave stations around Vieques, NDBC Station 41043 NE Puerto Rico was the most suitable. This station has a relatively long record from May 1, 2012, to the present. It is located approximately 170 nm to the

north of Vieques, and is the closest station in open water, exposed to the dominant easterly waves generated by Trade Winds and to seas and swell from the northeast.

The results of the typicality analysis indicated that the wave climate at NDBC Station 41043 NE Puerto Rico during the BDI was typical of the longer-term trend. Because the location of NDBC Station 41043 NE Puerto Rico is affected by the same weather systems as Vieques (e.g., Trade Winds and the North Atlantic Oscillation) the wave climate derived from measurements during the BDI can also be considered typical, as well as resulting waves at the BDI beaches and wave-induced currents. Furthermore, since wind is the main wave generation mechanism, it can be inferred that the wind climate and resulting wind-induced currents during the BDI were also typical. Based on the typicality analysis, it can be concluded that the beach changes and MEC surrogate burial and mobility observed during the BDI were typical. The details of the typicality analysis are included in **Appendix I**.

5.2 Storms

During the BDI, atypical wave conditions occurred on the south coast of Vieques during the passage of Tropical Strom Erika on August 28, 2015, and Hurricane Matthew on September 29, 2016. **Figure 5-1** and **Figure 5-2** show the tracks of Tropical Storm Erika and Hurricane Matthew, respectively. At Beaches 1 and 2, the most exposed BDI beaches on the south coast, corresponding atypical changes in beach profiles and shoreline positions occurred. The inspection of beach profiles before and after these storms showed that the shoreline retreat corresponded with the formation of a berm in the nearshore, suggesting that the dominant sediment transport direction at these beaches during these storms was cross-shore. Beaches 3, 4 and 19 did not experience any change due to the protection offered by their orientation and/or coastal features. Non-BDI beaches along the south coast with similar characteristics would have experienced similar responses.

In 2017, after the completion of the BDI, Vieques was impacted by two hurricanes within 2 weeks. Hurricane Irma, a Category 5 hurricane, passed approximately 35 nm to the northeast of Vieques on September 6, and Hurricane Maria, a Category 4 hurricane, passed approximately 10 nm to the southwest of Vieques on September 20. **Figure 5-3** shows the tracks of Hurricanes Irma and Maria, which tracked in a southeast to northwest direction.

Because the BDI was completed in December of 2016 and survey crews were evacuated from Vieques prior to the hurricanes, no immediate pre-hurricane beach and MEC surrogate surveys and wave measurements could be performed. However, a post-Maria beach reconnaissance was performed the week of October 23, 2017, supported by drone-based aerial imagery and video. Subsequently, beach surveys were performed at all BDI beaches between October 30 and November 7, 2017. In addition, a wave hindcast, combined with hydrodynamic modeling, was performed for Hurricane Maria (the most damaging of the two hurricanes) to estimate wave conditions and storm surge at the BDI beaches.

Hurricane Maria made landfall on the east coast of Puerto Rico at Yabucoa, approximately 15 nm (30 km) to the west-southwest of Vieques across the Pasaje Vieques with sustained winds of about 130 knots (240 km/h). The estimated 20 km radius to maximum winds, track direction and location relative to Vieques made Maria one of the most devastating hurricanes that hit Vieques in recent times, likely more devastating than Hugo which made landfall in Vieques in September of 1989 as a Category 3 hurricane. Hurricane Maria generated high waves and storm surge which were particularly damaging on Vieques' south coast.

As Hurricane Maria approached Vieques from the southeast, it approached and progressed to the northwest, its counterclockwise wind circulation generated northeasterly winds and waves on the north coast first, then easterly and finally southerly wind and waves on the east and south coasts, respectively. The direction and location of the hurricane track relative to Vieques produced longer wind durations from the southerly direction, which resulted in high waves and storm surge affecting the south coast for longer than elsewhere around Vieques. According to the wave hindcast, significant wave heights just offshore the BDI beaches were in the order of 6 m. This is consistent with the 6 to 7 m waves in deep water, inferred from the 1 m storm surge estimated by Rodriguez et al. (1994) for Hurricane Hugo, and wave heights in **Table 3-2**. At the time of the highest waves in the nearshore, wave conditions were as follows. Ranges of significant wave heights are given to provide a general idea of the magnitude of the wave heights in the nearshore.

- **South Coast**: significant wave heights were between 2 to 3 m at Beach 1, 1.5 to 2 m at Beaches 2, 3 and 19, and 1 m at Beach 4. Except at Beach 4 due to its southwest facing orientation, waves approached these beaches from the southeast and nearly perpendicular to the shore. Peak periods were approximately 14 seconds.
- **East Coast**: significant wave heights at Beach 12 and 14 were 2 m, from the east, and peak periods were approximately 13 seconds.
- **North Coast**: significant wave heights were 1 m at Beach 5, and 1.5 m at Beaches 22 and 24. At all beaches waves approached from the northeast, and peak periods were approximately 10 seconds.
- **West Coast**: significant wave heights at SWMU 4 were 2 m, from the southwest, and peak periods were approximately 13 seconds.

In addition, the large amount of seagrass found on the beaches during the post-Maria beach reconnaissance suggest that wind- and wave-induced currents were sufficiently strong to scour sediments from around seagrass roots and tear up extensive areas of seagrass, just as during Hurricane Hugo (Rodriguez et al., 1994).

Table 5-1 summarizes the parameters of the storms that passed near Vieques during and after the BDI.

The hydrodynamic modeling, which was performed with the wave hindcast, included the wave and wind setup, barometric pressure, and astronomical tide. It showed that the storm surge was the highest on the south coast of Vieques. The storm surge at the BDI beaches on the south coast ranged between 1 and 1.2 m. On the east coast, the storm surge at Beaches 12 and 14 was in the range of 0.9 to 1 m, and 0.6 to 0.7 m on the BDI beaches on the north coast. On the west end at SWMU 4, the storm surge on the southwest-facing coast was approximately 0.7 m, and 0.2 m on the west-facing coast. Overall, the storm surge estimates are consistent with the measurement shown in **Table 5-1** for Isabel Segunda. The tide gauge at Esperanza was damaged during Hurricane Maria and therefore no measurements were available to derive the storm surge at that location.

A summary of the wave hindcast and hydrodynamic wave model setup and estimates of wave conditions and storm surge at all BDI beaches are included in **Appendix I**. Significant wave heights were estimated from a wave hindcast, as noted above. Because the wave model was coupled with a hydrodynamic model that simulated the time- and space-varying water levels, water depths also varied. In the bullet list above, ranges of significant wave heights are given to provide a general idea of the magnitude of the wave heights in the nearshore at the BDI beaches. For additional detail, please see Figures I-19 through I-35 in **Appendix I**.

5.3 Water Levels

During the BDI, the variability of the MSL was relatively significant, because it was of approximately of the same magnitude as the tide range (e.g., MHHW – MLLW = 0.22 m). The highest water level recorded during the BDI, at 0.35 m MSL, occurred during the passage of Tropical Storm Erika on August 28, 2015. This high-water level combined with the storm's high waves resulted in the maximum shoreline retreat at Beaches 1 and 2, the most exposed BDI beaches on the south coast. The inspection of historical water level records measured at Vieques and vicinity showed that water levels during the BDI were typical, except during the passage of Tropical Storm Erika. Consequently, it can be concluded that the effect of the water level on the beach dynamics observed during the BDI was generally typical. **Figure 5-4** shows the water levels measured at NOAA Station 9752695 Esperanza for 2015 and 2016.

In addition to high waves, Hurricanes Irma and Maria (which occurred after the formal BDI was completed) generated high storm surges which compounded with the extremely high tide to generate high water levels. **Table 5-2** summarizes the water levels due to storms in Vieques during and after the BDI. For the storms listed, the difference between the storm surges in **Table 5-1** and the water levels in **Table 5-2** show that the wind and wave setup and barometric pressure are the drivers of water level in storm conditions in Vieques.

5.4 Rainfall

Figure 5-5 shows the daily rainfall measured during the BDI**. Figure 5-6** shows the derived monthly rainfall and **Figure 5-7** shows the derived annual rainfall (as a running total of the previous 12 months) compared to NOAA measurements at Roosevelt Roads (Naval Activity Puerto Rico) in Ceiba, across Pasaje Vieques, on the east coast of Puerto Rico.

The measurements confirmed that rainfall in Vieques varies monthly, the driest months are usually January through April, and monthly rainfall increases thereafter to peak in October. **Figure 5-6** shows that 2015 was dry year with monthly averages well below typical until late in the fall of 2015. Compared to monthly averages at Roosevelt Roads, 2016 was closer to a typical year through the winter and summer. A significant anomaly was the month of November, when it rained approximately 400 mm. By the end of 2016, the annual rainfall was comparable to that at Roosevelt Roads, and consistent with estimates cited in the literature.

During the BDI, except for the berm breaches by ephemeral streams and/or surface runoff on the east end of Beach 1 (see **Figures 5-8 and 5-9**), on the west end of Beach 24 (see **Figure 5-10**), and at Beach 22 (see **Figure 5-11**) following the extreme rainfall in November 2016, the survey crews did not observe lagoon inlets or ephemeral streams flowing to the bays, which could have redistributed sediment and altered beaches. In these three cases, the berm breaches produced only localized changes on the beach.

During the passage of Hurricane Irma, and subsequently during Maria, the rainfall gauge installed for the BDI at Camp Garcia was damaged and rainfall was not recorded. No public rainfall measurements were available for Vieques and vicinity during these events. The only estimate of rainfall during Hurricane Maria was given by NASA's Integrated Multi-satellitE Retrievals for Global Precipitation Measurement mission (IMERG; 2017). IMERG estimated that rainfall greater than 254 mm were common along Maria's track. The inspection of IMERG's online plots indicated that rainfall in Vieques was in the order of 200 to 300 mm.

Relative to the 100-year (660 mm) and the extreme November 2016 (400 mm) rainfalls, the rainfall during Hurricane Maria was not as extreme, but combined with the rainfall during Hurricane Irma, the rainy season of 2017, and the extreme rainfall event of November of 2016, it could have resulted in extreme water levels at various lagoons and within the watershed features near the beaches. During the beach reconnaissance performed the week of October 23, 2017, several beach berm breaches due to lagoon and ephemeral stream high water levels were identified, with various degrees of beach impact. As noted previously, this event occurred post-BDI, and represents an extreme condition, not conditions that would typically occur long-term.

Based on observations made during and after the BDI, it can be concluded that, in general, surface water runoff (lagoon and ephemeral flows) do not contribute to broad-based beach changes as a result of single and isolated extreme rainfall events, but do result in localized beach changes when a series of extreme events combine in a relatively short time (e.g., within 1 year).

5.5 Beach Dynamics

The following were analyzed to assess the dynamic behavior of the BDI beaches, during the BDI and after Hurricanes Irma and Maria:

- Beach profile
- Depth of closure
- Landward limit of beach change
- Shoreline position
- Surface water runoff
- Sediment characteristics
- Wave and wind conditions

The beach profiles measured along the transects in easting, northing and elevation were converted to a transect coordinate system and referred to by their corresponding transects. For a given beach, profiles in the plane of the transect allowed for the analysis of changes in time and space in the cross-shore direction, and profiles along all transects allowed for analysis of changes in the longshore direction.

Of importance for the BDI is the definition of the areas of potential beach change, as the burial and mobility of MEC in these areas could be significantly affected by the processes that drive the beach changes. These areas are bounded by the depth of closure in the nearshore and the landward limit of beach change in the backshore. Beyond these limits, no significant changes are expected to occur in typical conditions. The depth of closure (and landward limit of beach change) were identified by evaluation of the measured profiles and through the analysis of aerial photos. Beyond the depth of closure, no significant changes in bottom elevation are expected in typical wave conditions. It is relatively simple to identify the depth of closure by visual inspection of profiles at beaches fronted by broad sandy bottoms, like Beach 1, where measured beach profiles would collapse at the depth of closure. However, this is not as straightforward at beaches which are fronted by combinations of sandy, reef and seagrass bottoms. Furthermore, there are inherent challenges in measuring the beach profiles precisely on a transect from a survey boat in a seaway, together with the “false” returns from seagrass and rocky bottoms, both of which affect the repeatability of the measurements, leading to the bottom changes noted beyond the depth of closure. However, in these instances the depth of closures identified represent a good approximation, sufficient for the objectives of the Beach Dynamics Investigation and use of its data.

For each beach, the locations of the depth of closure and landward limit of beach change at each transect were used to map the corresponding contours and define the area along the beach where sediment transport and beach changes occurred for the conditions present during the BDI and Hurricane Maria. This area is referred to as the “area of beach change,” and was characterized at each transect by its width relative to the depth of closure location. Similarly, the measured profiles were used to compute the shoreline position at the PRVD02 (same as MSL) for all transects. The computed shoreline positions were used to compute the range of horizontal shoreline position change at each transect and to map contours of monthly shoreline positions along the beach. Finally, the measured profiles were also used to compute, at each transect, the maximum beach elevation change, its range, location, and high and low elevations relative to PRVD02.

The following analyses pertain to the metocean conditions during the BDI. The wind and wave conditions during the BDI were assessed as typical (see **Appendix I)** and were determined from field observations (see **Appendix G**). Details of the information discussed in the tables can be seen in the figures referenced and/or in the additional figures in **Appendix J**. Observations and conclusions from the post-Maria beach reconnaissance performed the week of October 23, 2017, and beach surveys performed between October 30 and November 7, 2017, are included were applicable and would be representative of similar extreme metocean conditions. Wave conditions during Hurricane Maria were determined from the wave hindcast described in **Appendix I**.

- **Tables 5-3 to 5-8** summarize the beach dynamic analyses for LIA UXO 2 Beaches 2, 3, 4, 5, 12 and 14
- **Tables 5-9 to 5-11** summarize the beach dynamic analyses for North EMA and SIA UXO 7 Beaches 22 and 24
- **Tables 5-12 and 5-13** summarize the beach dynamic analyses for South SIA UXO 8 Beaches 1 and 19
- **Table 5-14 and 5-15** summarize the beach dynamic analyses for SWMU 4
- **Figures 5-12 to 5-17** show, for LIA UXO 2 Beaches 2, 3, 4, 5, 12 and 14 and conditions present during the BDI:
  - pre-Maria aerial photos
  - contours of depth of closure
  - contours of landward limit of beach change
  - contours of shoreline positions (and range of horizontal shoreline change)
  - maximum beach elevation changes

- **Figures 5-18 to 5-20** show corresponding views and contours for North EMA and SIA UXO 7 Beaches 22 and 24
- **Figures 5-21 and 5-22** represent South SIA UXO 8 Beaches 1 and 19
- **Figures 5-23 and 5-24** represent SWMU 4
- **Figures 5-25 through 5-37** show (remaining Section 5 figures referenced in individual tables), for all beaches:
  - post-Maria aerial photos
  - BDI contours of depth of closure, landward limit of beach change and shoreline positions
  - post-Maria shoreline position and landward limit of beach change

All beach changes during the BDI can be considered typical because their drivers (e.g., the wave and wind climates, water levels and resulting currents) were typical during the BDI (see **Appendix I**). Beach changes following the BDI (during Hurricane Maria) were atypical. BDI results and analyses along with beach profiles are included in **Appendix J**.

5.6 MEC Surrogate Surveys

This subsection summarizes the MEC surrogate surveys and the analyses performed to assess their burial and mobility during the BDI. Detailed results and analyses of these surveys are included in **Appendix K**. The following were analyzed:

- Measured and predicted depth of burial of MEC surrogates
- Potential of MEC burial and mobility
- MEC surrogate displacements
- Time to achieve complete burial

In areas bounded by the depth of closure and the landward limit of beach change (i.e., the area of beach change), waves and currents combined with the beach-wide changes that these induce, increase the likelihood of MEC mobility and depths of burial beyond the depths that could result from the interaction of MEC and waves and currents alone (Wilson et al., 2008). Seaward of the depth of closure, where the bottom would not change in typical conditions, MEC may or may not self-bury to shallow depths (e.g., one diameter of the MEC width) or exhibit mobility, depending on depth, waves, currents, bottom conditions. These areas were identified for the BDI beaches and, from these, similar areas could be inferred for non-BDI beaches in Vieques that feature similar conditions and characteristics. The burial condition and mobility of the MEC surrogates in those areas during the BDI were compared to predictions from empirical formulas to assess the adequacy of those formulas to assist in future conceptual-level investigations, remediation planning, formulation of land use and engineering controls, and frequency of monitoring.

Among the several formulas available for the prediction of the depth of burial (B_d) (Cataño-Lopera et al. 2006, Sumer et al. 2001, and Demir et al. 2007) which depend on the Keulegan-Carpenter (KC) or Reynolds (Re) numbers or Shields parameter, the formula by Demir et al. (2007) dependent on the Shields parameter combined with the range of vertical bottom change measured at the BDI beaches, produced the best correlation between measured and predicted depths of burial. For perpendicular wave-induced flow on cylinders on sandy bottom, the formula by Demir et al. (2007) is given by:

$$B_d / D = 2\,\Theta^{0.8}$$

where B_d is the depth of burial, D is the diameter of the cylinder, and Θ is the Shields parameter. The Shields parameter is a function of the wave height and period, water depth, and the mean diameter (D_{50}) of the bottom sediment (see **Appendix K**).

Depths of burial were measured in September 2016 when the acoustic transmitters on the surrogates were replaced on site by divers, and in July 2017 when the surrogates were recovered. In general, this approach

predicted the burial condition (buried or not buried) very well. However, discrepancies between predicted and measured depths of burial were noted, as expected. The formula by Demir et al. (2007), like most similar formulas, assumes cylinders are oriented perpendicular to the wave direction and on sandy bottoms. This is not the case for the MEC surrogates, for which shapes, while elongated, are not cylindrical, may or may not be perpendicular to the wave direction, and not all rested on sandy bottoms (i.e., some with various densities of seagrass, rocks, shells, etc.). Furthermore, the depth of burial measurements were performed relative to bottom. Because bottoms are irregular, an average bottom for reference is therefore not precise.

The potential of the wave conditions present during first year of the BDI (2015) to bury and move MEC at the surrogate locations was analyzed by comparing empirical estimates with measurements. At each surrogate location, water depths, sediment sizes, and surrogate diameter and density were used with a wave hindcast for 2015 to derive hindcasts of enhanced bottom shear stress due to waves, and mobility parameter (MP) as defined by Friedrichs (2015). For the typical wave conditions of 2015 and the atypical condition generated by Tropical Storm Erika, averages and maxima were used with criteria for incipient burial and mobility and compared to measurements. In general, the enhanced bottom shear stress and the MP estimated well the potential of the waves to bury and move MEC, respectively. However, discrepancies between the estimates and measurements were noted, as expected, because both assume cylinders are oriented perpendicular to the wave direction and on sandy bottoms, which are conditions different than those of the surrogates.

Despite the discrepancies between estimates and measurements, the enhanced bottom shear stress due to waves and the MP provided a good indication of the burial condition, order of magnitude of the depth of burial of the surrogates, and the potential of the waves to bury or move the MEC types deployed in the BDI. These tools can be used to predict/understand where MEC could be present, explain observations from other studies (e.g., Wide Area Assessment [WAA]), and plan future investigations and removal/remedial actions, as warranted.

The following summarizes analyses of measurements, surveys, and predictions of depth of burial and mobility of the MEC surrogates deployed at the BDI beaches, grouped by their exposure to the same wave climate (i.e., beaches on the same coast). These analyses are based on a wave hindcast for 2015 performed by CH2M HILL, which was a typical year in Vieques with regards to metocean conditions, and which was computed using the AWAC measurements. Consequently, resulting depth of burial and mobility measurements and estimates can only be considered representative of that period. Tropical Storm Erika on August 28, 2015, generated atypical conditions at the south coast beaches, and depths of burial and mobility during that event could also be considered atypical, but not representative of an extreme event such as a hurricane.

On the south coast of the VNTR, MEC surrogates were deployed within and outside the area of beach change at LIA UXO 2 Beaches 2 and 4 and South SIA UXO 8 Beaches 1 and 19, and at LIA UXO 2 Beach 3 within the area of beach change. The analysis indicated that within the area of beach change and in typical conditions, the surrogates did not move, but self-buried to various degrees, in some cases deeper than one surrogate diameter due to beach-wide bottom changes, or bottom fluidization where the bottom sediment was very fine. Outside the area of beach change, in typical conditions, the surrogates in general did not move and remained minimally or not buried. Observations support the notion that the surrogates did not move during Tropical Storm Erika or Hurricane Matthew.

On the east coast of the VNTR, MEC surrogates were deployed outside the area of beach change at LIA UXO 2 Beach 14. The analysis indicated that in typical conditions and depending on type, the surrogates moved or remained in place, but all self-buried to a shallow depth. In a typical winter, conditions could be conducive to mobility, depending on type of MEC.

On the north coast of the VNTR, MEC surrogates were deployed within and outside the area of beach change at LIA UXO 2 Beaches 5 and EMA and North SIA UXO 7 Beaches 22 and 24. Despite being exposed to the same wave climate, the depth of burial and mobility of surrogates was diverse due to the different coastal features and conditions at these beaches. At Beach 5, most surrogates did not move and self-buried to a shallow depth, except for most surrogates in the western end of the beach which moved and remained minimally or not buried. At Beach 22, outside the area of beach change and in typical conditions, the surrogates located offshore did not

move and remained minimally or not buried, while those located in the nearshore at Beach 22 East did not move and self-buried initially and deeper afterwards, hypothetically, by bottom fluidization because of very fine bottom sediment. At Beach 22 West, at the edge of the depth of closure, surrogates located within the area of beach change did not move, but self-buried to a shallow depth initially and deeper afterwards due to beach-wide bottom changes or, hypothetically, by bottom fluidization. At Beach 24, surrogates within the area of beach change moved shoreward, self-buried to a shallow depth initially, and deeper afterwards due to bottom changes in the sand channel. Surrogates outside the area of beach change moved and were found, not buried, but resting on rocks. In all cases, winter conditions were not conducive to mobility of the surrogates. The sand channel at Beach 24 appeared to be a key feature for surrogate mobility at this beach, and possibly a proxy for the similar behavior of MEC at other beaches.

At all locations where the surrogates were deployed on a sandy bottom, the conditions during the BDI were conducive to the self-burial of the surrogates, which were fully or almost fully buried within different timeframes. Times to fully burial varied from beach to beach and surrogate type, and no difference was found among the VNTR coasts. However, the quickest times to fully buried were at Beaches 1, 2, 3, 14, 22 and 24 (71 to 200 days) with longer times at Beaches 4, 5 and 19 (182 to 595 days). In general, dynamic beaches showed the quickest times to fully burial while the stable beaches the longest. Exceptions to the this were Beaches 3 and 22 which were both found to be stable, with a low wave environment, but where sediment size could be small enough to allow the self-burial of the surrogates by bottom fluidization.

The following conclusions are made for intact MEC of characteristics and shapes similar to those deployed in the BDI.

- Depth of burial is a function of the MEC characteristics (size, weight, shape) and condition (orientation), bottom type (sand, seagrass, reef), grain size (if sandy bottom), water depth, wave conditions and beach dynamics.
- MEC will remain on top of hard bottoms, remain or partially self-bury in seagrass bottoms, and partially or self-bury completely in sandy bottoms.
- In typical wave conditions and sandy bottoms, the tendency of MEC is to self-bury, depending on the water depth. The depth of burial depth decreases as the water depth increases.
- MEC located in areas of beach change (e.g., landward of the depth of closure) would tend to self-bury deeper (more than one diameter) due to beach-wide bottom changes.
- Except for when in extreme wave conditions, MEC located seaward of the depth of closure would not exhibit mobility because its weight-to-drag ratio would be higher than that of the bottom sediment, and buried MEC will remain buried.
- In areas of very fine sediment (e.g., less than 0.1 mm), relatively heavy MEC could self-bury deep (more than one diameter) due to bottom fluidization. This burial process has been described by Baeye et al. (2012), Brandes (1999), Brandes et al. (2002), Brandes et al. (2004), Plager (2000) and Richardson et al. (2001).
- In typical wave conditions, MEC at dynamic beaches will self-bury as soon as within 71 days and as late as 200 days from impact.
- In typical wave conditions, MEC at stable beaches will self-bury as soon as within 182 days and as late as 595 days from impact, or potentially never.
- The sand channel at Beach 24 appeared to be a key feature for surrogate mobility at this beach, and possibly a proxy for the similar behavior of MEC at other beaches.

TABLE 5-1
Parameters of Storms that Passed Near Vieques During and After the BDI
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Storm	Date	Distance [a]	Sustained Wind Speed [b]	Hs	Tp	MWD	Storm Surge [c]	
							Esperanza	Isabel Segunda
Tropical Storm Erika	8/28/15	60 nm	45 knots	4.1 m [d]	8.9 sec [d]	128 deg [d]	0.22 m	0.25 m
Hurricane Matthew	9/29/16	250 nm	50 to 60 knots	3.0 m [e]	9.1 sec [e]	117 deg [e]	0.18 m	0.15 m
Hurricane Irma	9/6/17	35 nm	160 knots	4.5 m [f]	11.4 sec [f]	107 deg [f]	0.38 m	0.50 m
Hurricane Maria	9/20/17	10 nm	130 knots	6.4 m [f]	6.7 sec [f]	105 deg [f]	N/A	0.87 m

a. track to Vieques
b. NOAA National Hurricane Center
c. peak water level anomaly (= measured – predicted) at NOAA Stations 9752695 Esperanza and 9752619 Isabel Segunda
d. measured at AWAC-S
e. measured at NDBC Station 41052 South of St. John
f. measured at NDBC Station 41056 Vieques Island

deg = degree
Hs = significant wave height
m = meter
MWD = mean wave direction (from)
nm = nautical mile
sec = second
Tp = peak wave period

TABLE 5-2
Water Levels in Vieques due to Storms During and After the BDI
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Storm	Date	Distance	Sustained Wind Speed	Water Level (MSL)	
				Esperanza [a]	Isabel Segunda [b]
Tropical Storm Erika	8/28/15	60 nm	45 knots	0.35 m	0.43 m
Hurricane Matthew	9/29/16	250 nm	50 to 60 knots	0.27 m	0.31 m
Hurricane Irma	9/6/17	35 nm	160 knots	0.46 m	0.51 m
Hurricane Maria	9/20/17	10 nm	130 knots	N/A	0.81 m

a. NOAA Station 9752695
b. NOAA Station 9752619

m = meter
nm = nautical mile

TABLE 5-3
Beach Dynamics Analysis for Beach 2 (Unnamed, UXO 2)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

	Analysis
Dynamics	Due to its exposure to the predominant refracted waves from the southeast and storm waves from the south this beach is dynamic. However, not as dynamic as Beach 1 due to the wave protection offered by a reef at the eastern end of the bay, and an island to the southeast.
Beach Profiles	The average maximum elevation change of the beach profiles was approximately 0.9 m landwards of the shoreline. The bottom slopes are even along the beach. The tombolo formed by the small island at the eastern end is dynamic with changes in elevation of up to 1 m. South of the island along transect 9, the bottom was stable. Hurricane Maria moved large amounts of sediment, likely and predominantly from the beach to the nearshore up to and beyond the depth of closure, but possibly also from offshore; and sediment supply from Laguna Icacos (see Surface Water Runoff below).
Area of Beach Change	The width of the area of beach change varied between 66 and 82 m. The widest areas were at the ends of the beach and the narrowest at the center at transect 4.
Depth of Closure	The contour is approximately parallel to the shoreline and borders a large seagrass patch. The depth of closure is shallow and ranges between -2 and -3 m. Depths of closure are deeper, -2.6 and -2.9 m, at the western and eastern ends, respectively, and shallower in the center at -2.2 m at transects 4 and 5.
Landward Limit of Beach Change	The contour is uniform and approximately parallel to the shoreline bordering the vegetation line. No significant changes in elevation are noted along the contour and the average elevation was approximately 1 m. Hurricane Maria eroded the beach and vegetation up to elevations between 0.8 and 1.4 m and moved the contour inland approximately 15 m. Aerial photos after Hurricane Maria showed changes inland beyond the contour, but these are attributed to transport of sand and erosion of vegetation by wind.
Shoreline Position	Shoreline positions varied uniformly along the beach suggesting a dominant cross-shore transport of sediment. The maximum range of shoreline position change was in the order of 14 to 15 m at the ends of the beach, decreasing to 8 to 9 m at transects 6 and 7. Similar to Beach 1, the maximum retreat of the shoreline occurred after Tropical Storm Erika and Hurricane Matthew. After Hurricane Maria, however, the shoreline did not retreat as much and remained within the range of shoreline positions during the BDI. The inspection of beach profiles before and after these storms showed that the shoreline retreat corresponded with the accretion of sediment in the nearshore, suggesting that cross-shore was the dominant transport direction during these storms.
Surface Water Runoff	No beach wide impact. However, rainfall during Hurricane Maria flooded Laguna Icacos on the east end of the beach and excess water flowed to the beach from the lagoon through the strafing target breaching the berm (transect 7, see **Figure 5-38**). At the west end, the small ephemeral stream at transect 1 also breached the beach berm (see **Figure 5-39**). In both cases, only localized beach changes were observed.
Sediment	The size of the backshore sediment is uniform and varies between 0.16 and 0.18 mm (fine sand). It is similar to the shoreline sediment, which varies between 0.14 and 0.17 (fine sand). The size of the nearshore sediment is uniform and very fine in the order of 0.11 mm (very fine sand). In the nearshore, nearly 90% of the sediment is finer than 0.2 mm and nearly 10% of the sediment is silt. The gradation of the sediment from relatively coarse on the beach to fine in the nearshore is typical.
Wave Conditions	Typical 0.5 m, up to 1 m, 3 to 7 seconds from the southeast. The estimated maximum significant wave height during Hurricane Maria was 2 m, 14-second peak period from the southeast.
Wind Conditions	Typical 10 to 15 knots from the east-southeast, occasionally 20 knots. Winter wind direction from the north.

TABLE 5-4
Beach Dynamics Analysis for Beach 3 (Playa Salinas del Sur, UXO 2)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

	Analysis
Dynamics	Due to the wave protection offered by a reef to the southeast and an island to the south this beach is stable.
Beach Profiles	Beach profiles showed very small changes in the nearshore. However, relatively large changes were apparent at the shoreline where the average maximum elevation change of the beach profiles was approximately 0.6 m. The bottom slopes are similar along the beach. Hurricane Maria moved sediment to the nearshore, possibly from offshore, given that there were no significant changes landwards of the shoreline.
Area of Beach Change	The width of the area of beach change varied between 95 and 115 m which seems wide for the relatively small waves at this beach. The changes in bottom elevation in the nearshore were small and in the order of 0.2 m. This made the identification of the location of the depth of closure challenging.
Depth of Closure	Given the small changes in the bottom elevation in the nearshore, the exact location of the depth of closure was difficult to determine. Actual changes in the profiles are of a similar magnitude as potential differences introduced by the inherent resolution and repeatability limitations of the surveys. For the small wave conditions at this beach, the depth of closure ranging between -1.7 and -1.9 m is deeper than anticipated. The contour is not parallel to the shoreline and is in an area where the depth is uniform and the incident waves have a normal angle of approach to the shore and depth contours.
Landward Limit of Beach Change	The contour is uniform and parallel to the shoreline away from the vegetation line. No significant changes in elevation are noted and the average elevation was approximately 0.8 m. Hurricane Maria eroded the beach and vegetation up to an elevation of about 1 m and moved the contour inland approximately 10 m. Aerial photos after Hurricane Maria showed changes inland beyond the contour, but these are attributed to transport of sand and erosion of vegetation by wind.
Shoreline Position	Shoreline positions varied uniformly along the beach suggesting a dominant cross-shore transport of sediment. The maximum range of shoreline position change was in the order of 8 to 10 m, which is larger than anticipated for the small wave conditions observed at this beach. The maximum retreat of the shoreline did not occur after Tropical Storm Erika or Hurricane Matthew, as it did at neighboring Beach 2. Large mounds of Sargassum formed along the shoreline, growing in May 2015 to eventually disappearing in November/December 2015. The presence of these mounds created atypical conditions as beach sediment landward of the shoreline was protected by the mounds and incoming waves reflected seaward combining with incident waves to augment sediment transport, in particular, at the seaward edge of the mounds (i.e. at the shoreline). After Hurricane Maria, the shoreline moved to an extreme seaward location, approximately 3 m seaward from its most seaward location during the BDI. Given the relatively small changes of the beach profiles in the backshore, it is likely that Hurricane Maria transported sediment from offshore.
Surface Water Runoff	No impact.
Sediment	The size of the backshore sediment is uniform and varies between 0.15 and 0.16 mm (fine sand). It is similar to the shoreline sediment, which is in the range of 0.14 to 0.15 (fine sand). An outlier of nominal diameter 0.24 mm is noted in the shoreline for the first sample. The size of the nearshore sediment is uniform and very fine in the order of 0.11 mm (very fine sand). In the nearshore, nearly 90% of the sediment is finer than 0.2 mm and nearly 20% of the sediment is silt. The gradation of the sediment from relatively coarse on the beach to fine in the nearshore is typical.

TABLE 5-4
Beach Dynamics Analysis for Beach 3 (Playa Salinas del Sur, UXO 2)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

	Analysis
Wave Conditions	Typical less than 0.5 m, up to 1 m, 3 to 7 seconds from the south-southeast. The estimated maximum significant wave height during Hurricane Maria was 1.5 m, 14-second peak period from the southeast.
Wind Conditions	Typical 10 to 15 knots from the east-southeast.

TABLE 5-5
Beach Dynamics Analysis for Beach 4 (Turtle Beach/Playa Carrucho, UXO 2)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

	Analysis
Dynamics	Due to its orientation to the southwest and wave protection offered by a reef to the southeast and an island to the south this beach is stable.
Beach Profiles	Beach profiles showed negligible changes. The average maximum elevation change of the beach profiles was approximately 0.3 m and predominantly along the shoreline, except at transect 2. At transect 2 the maximum elevation change was landwards of the shoreline possibly, due to the effect of vehicular traffic. The bottom slopes gradually decrease from relatively steep to gentle from the northwestern to the southeastern end. The gentle slopes on the south end of the beach are likely the result of the supply of sediment from Laguna Anones (which has been reported to breach the beach berm only during intense major hurricane rainfall) and the protection offered by the reef to the southeast. Hurricane Maria moved sediment to the nearshore, possibly from offshore and supply from Laguna Anones (see Surface Water Runoff below), given that the beach landwards of the shoreline did not experience significant changes.
Area of Beach Change	The width of the area of beach change is relatively narrow, consistent with a stable beach. It varied between 28 and 38 m, with the narrowest area at transect 2.
Depth of Closure	The contour is approximately parallel to the shoreline and depths of closure are relatively shallow suggesting small waves which is consistent with observations. Depths of closure decrease gradually from the northwestern to the southeastern end, from -1.8 to -1.1 m, suggesting that waves on the northwest end are typically higher than on the southeastern end.
Landward Limit of Beach Change	The contour is uniform and parallel to the shoreline away from the vegetation line. No significant changes in elevation are noted and the average elevation was about 0.9 m. Hurricane Maria eroded the beach and vegetation up to elevations that ranged between 0.6 m and 1.6 m and moved the contour inland approximately 9.6 m. Aerial photos after Hurricane Maria showed changes inland beyond the contour, but these are attributed to transport of sand and erosion of vegetation by wind.
Shoreline Position	Shoreline positions varied uniformly along the beach and in a very narrow 1.1 to 1.4 m range suggesting negligible beach changes. No retreat of the shoreline occurred after Tropical Storm Erika or Hurricane Matthew, as it did at neighboring Beach 2, suggesting that similar storms would have similar negligible effect on this beach. This was confirmed given that after Hurricane Maria, the shoreline did not retreat and remained within the range of shoreline positions during the BDI.
Surface Water Runoff	No beach-wide impact. However, rainfall during Hurricane Maria flooded Laguna Anones on the southeast end at transect 6 (see **Figure 5-40**), and excess water flowed to the beach breaching the berm. Only localized beach changes were observed.
Sediment	The size of the backshore sediment is uniform and varies between 0.18 and 0.21 mm (fine sand). The size of the shoreline sediment is similar and in the range of 0.15 to 0.16 (fine sand). An outlier of nominal diameter 1 mm is noted in the shoreline for the second sample. The nearshore sediment size is uniform and varies between 0.12 and 0.16 mm (fine sand). An outlier of nominal diameter 0.3 mm is noted in the nearshore for the second sample. The gradation of the sediment from relatively coarse on the beach to fine in the nearshore is typical.
Wave Conditions	Typical less than 0.5 m, 6 seconds from the south-southeast. The estimated maximum significant wave height during Hurricane Maria was 1 m, 14-second peak period from the southeast.
Wind Conditions	Typical 10 to 15 knots from the east-southeast.

TABLE 5-6
Beach Dynamics Analysis for Beach 5 (Icacos, Playa Yallis, UXO 2)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

	Analysis
Dynamics	Due to the wave protection offered by the long 1 to 2 m deep barrier reef to the north, the reef extending from the headland to the east, and Yallis Island to the northwest this beach is stable.
Beach Profiles	Most profiles showed negligible changes, except at the western end. The average maximum elevation change of the beach profiles between transects 1 to 7 was approximately 0.5 m and predominantly along the shoreline, and 1.2 m between transects 8 and 10 seawards of the shoreline. Most profiles are flat and show a steep drop into the bay at approximately 15 m from the shoreline. This drop gradually disappears to the west of transect 7. Hurricane Maria moved sediment to the nearshore, possibly from offshore, given that the beach landwards of the shoreline did not experience significant changes.
Area of Beach Change	Along most of the beach, the width of the area of beach change was relatively narrow and consistent with a stable beach. It varied between 16 and 20 m, and increased significantly to the west from transect 7 reaching a maximum of 47 m at transect 10.
Depth of Closure	The contour is approximately parallel to the shoreline and depths of closure are relatively shallow, suggesting small waves, which is consistent with observations. Depths of closure increase gradually from the eastern to the western end, from -0.9 to -1.2 m, suggesting that waves on the western end are typically higher than on the eastern end.
Landward Limit of Beach Change	The contour is uniform and parallel to the shoreline bordering the vegetation line. No significant changes in elevation are noted and the average elevation was in the order of 0.8 m. Hurricane Maria eroded the beach and vegetation up to an elevation of approximately 0.9 m and moved the contour inland approximately 9 m at transect 5, and 3 to 5 m at the western and eastern ends, respectively. Aerial photos after Hurricane Maria did not show changes inland beyond the contour.
Shoreline Position	Shoreline positions varied uniformly along the beach in a narrow 2 to 3 m range up to transect 7 to then widen to 14 and 11 m at transects 9 and 10, respectively. The western end of the beach (west of transect 7) is clearly shaped by the sediment transport forced by easterly wind-generated waves within the bay, and the offshore waves that refract around Yallis Island and move sediment back into the bay. After Hurricane Maria, the shoreline did not retreat and remained within the range of shoreline positions during the BDI.
Surface Water Runoff	No impact.
Sediment	The size of the backshore sediment is uniform and varies between 0.20 and 0.22 mm (fine sand). It is finer than the shoreline sediment which is in the range of 0.22 to 0.28 (fine and medium sand). The size of the nearshore sediment is uniform and varies between 0.25 and 0.29 mm (medium sand). The gradation of the sediment from relatively fine on the beach to coarse in the nearshore is not typical, but is likely due to the absence of typical wave-induced sorting due to the small waves in the bay.
Wave Conditions	Typical less than 0.5 m, 5 seconds from the northeast. The estimated maximum significant wave height during Hurricane Maria was 1 m, 11-second peak period from the northwest.
Wind Conditions	Typical 10 to 15 knots from the east.

TABLE 5-7
Beach Dynamics Analysis for Beach 12 (Unnamed, UXO 2)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

	Analysis
Dynamics	Due to its exposure to the predominant easterly waves, and waves from the northeast during the winter this beach is dynamic.
Beach Profiles	Beach profiles showed relatively large changes landwards of the shoreline. The average maximum elevation change of the beach profiles between transects 2 to 4 was approximately 2.2 m. At transect 1, at 1.2 m, it was significantly less possibly due the protection of the headland to the east. The beach faces (slopes landward of the shoreline) are relatively steep due to the coarse sediment size. Significant profile changes are noted seaward of the shoreline at transect 4 at the northwestern end and to a lesser degree at transect 2. No significant erosion or accretion of sediment was noted after Hurricane Maria.
Area of Beach Change	The width of the area of beach change is narrower in the southeastern area of the beach at approximately 89 m, and wider in the northwestern area at around 114 m. This is due to the presence of shallow reef at the eastern end of the beach which surfaces close to the shore and anchors the location of the depth of closure in that area.
Depth of Closure	The contour is approximately parallel to the shoreline. Depths of closure increase from the southern to the northern end. In the southern end and center of the beach depths of closure are in the order of -2.7 m, whereas in the northern end approximately -3.6 m.
Landward Limit of Beach Change	The contour is uniform and runs parallel to the shoreline reaching the vegetation line. No significant changes in elevation are noted and the average elevation was about 2.1 m. Hurricane Maria eroded the beach and vegetation up to an elevation of 2.4 m and moved the contour inland approximately 7 m. Aerial photos after Hurricane Maria did not show changes inland beyond the contour.
Shoreline Position	Shoreline positions showed large changes around the center of the beach at transects 2 and 3, of 14.6. m and 12.5 m, respectively. Changes at the northwestern end were larger (11.8 m) than at the southeastern end (7.1 m). Between transects 3 and 4 there is a location where the range of shoreline change is minimal (i.e. a pivot point), of approximately 5 m. Pivot points are locations of relative beach stability and represent transition from erosion to accretion. This, and the beach profiles, suggest that sediment moves along the shore in a cyclical fashion and the shoreline position (and the beach) adjusts to the seasonal changes in wave direction. An inspection of the shoreline positions showed that, at northwestern end, the beach retreats from January to March and advances seaward during the rest of the year, and vice versa at the opposite end. After Hurricane Maria, the shoreline remained within the range of shoreline positions during the BDI.
Sediment	Ranging between 0.34 and 0.52 mm (medium to coarse sand), the sediment size in the backshore is not uniform and coarser than sediments at other BDI beaches. At the shoreline, the sediment size is more uniform, in the range of 0.32 to 0.40 mm (medium sand). The relatively coarse sediment creates the steep beach faces at this beach. In the nearshore, the sediment size is uniform and finer, in 0.18 to 0.23 mm range (fine sand). The gradation of the sediment from coarse on the beach to fine in the nearshore is typical.
Surface Water Runoff	No impact.
Wave Conditions	Typical between 1 and 1.5 m, occasionally 2 m, 5 to 7 seconds, occasionally 10 seconds, from the east to southeast in in the summer, and northeast in the winter. The estimated maximum significant wave height during Hurricane Maria was 2 m, 13-second peak period from the east.
Wind Conditions	Typical 10 to 15 knots from the east, up to 20 knots. Occasionally from the south and southwest.

TABLE 5-8
Beach Dynamics Analysis for Beach 14 (Playa Brava, UXO 2)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

	Analysis
Dynamics	Due to its exposure to the predominant easterly waves, and waves from the northeast during the winter this beach is dynamic.
Beach Profiles	Beach profiles showed relatively large changes along the shoreline. The average maximum elevation change of the beach profiles was approximately 2.7 m. Landward of the shoreline, the beach slopes are relatively steep due to the coarse sediment size. No significant erosion or accretion of sediment was noted along the shoreline and landwards after Hurricane Maria, but some accretion in the nearshore possibly from onshore transport.
Area of Beach Change	The width of the area of beach change ranged between 94 and 113 m.
Depth of Closure	The contour is parallel to the shoreline. Depths of closure decrease from the southern to the northern end. In the southern end and center of the beach depths of closure are in the order of -4.1 m, whereas in the northern end approximately -2.7 m.
Landward Limit of Beach Change	The contour is uniform and parallel to the shoreline reaching the vegetation line. The elevation at the ends is relatively low around 2 to 2.5 m, peaking at about 4.3 m at transect 3 at the center of the beach. The average elevation was 3.1 m. Hurricane Maria eroded the beach and vegetation up to an elevation of 3.4 m and moved the contour inland approximately 1.9 m. Aerial photos after Hurricane Maria did not show changes inland beyond the contour.
Shoreline Position	Shoreline positions showed large changes at the ends of the beach, in the order of 28 m. At transect 3, at the center of the beach, the range is minimum (i.e. a pivot point) and approximately 8.5 m. This, and the beach profiles, suggest that sediment moves along the shore in a cyclical fashion and the shoreline position (and the beach) adjusts to the seasonal changes in wave direction. An inspection of the shoreline positions showed that, at northern end, the beach retreats from December to March and advances seaward during the rest of the year, and vice versa at the opposite end. After Hurricane Maria, the shoreline remained within the range of shoreline positions during the BDI.
Surface Water Runoff	No impact.
Sediment	Ranging between 0.44 and 0.58 mm (medium to coarse sand), the sediment size in the backshore is not uniform and coarser than sediments at other BDI beaches. At the shoreline, the sediment is similar and ranges from 0.46 to 0.60 mm (medium to coarse sand). The relatively coarse sediment results in steep beach faces at this beach. Except for an outlier sample (0.35 mm), the sediment size in the nearshore is uniform but approximately of the same size as in the backshore and shoreline, 0.59 to 0.61 mm (coarse sand). The sediment size is approximately the same in the cross-shore direction. This is not typical and likely reflects the effect of the complex interaction of waves, sediment, and the shallow reefs at this beach.
Wave Conditions	Typical between 0.5 and 2 m, 5 to 7 second, occasionally 11 seconds, from the east to southeast in in the summer, and northeast in the winter. The estimated maximum significant wave height during Hurricane Maria was 2 m, 13-second peak period from the east.
Wind Conditions	Typical 10 to 15 knots from the east, up to 20 knots. Occasionally from the south and southwest.

TABLE 5-9
Beach Dynamics Analysis for Beach 22 (east) (Puerto Diablo, UXO 7)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

	Analysis
Dynamics	Due to the wave protection offered by the rocky headlands and reefs at each side, which form narrow channels where the predominant refracted waves from the northeast refract and break this beach is stable.
Beach Profiles	Most profiles showed small changes, except at transect 3 where changes in elevation of up to 1.1 m were noted in the nearshore. The average maximum elevation change of the beach profiles was approximately 0.8 m. At transect 3 a large outcrop occasionally surfaces up to the headland at transect 6. At transect 3, there is steep drop just seaward of the shoreline due to the rock outcrop and the bottom is flat beyond it. The headland area (transect 6) is dynamic, and the shoreline position there showed changes in the order of 10 m. No other transects showed similar changes. The headland is a very complex feature where waves run on a reef and break on the shore from different directions and this results in changes that are not representative of the rest of the beach. No significant erosion or accretion of sediment was noted along the shoreline and landwards after Hurricane Maria, but some accretion was noted in the nearshore possibly from onshore transport.
Area of Beach Change	The width of the area of beach change varied between 59 to 86 m. The widest area is at the eastern end of the beach.
Depth of Closure	The contour is parallel to the shoreline. Its determination was difficult due to the relatively small bottom changes at some transects, the presence of a sand channel and reefs, and the inherent resolution and repeatability limitations of the surveys. The estimated depth of closure ranges between -2 and -2.9 m.
Landward Limit of Beach Change	The contour is uniform and parallel to the shoreline bordering the vegetation line. Changes up to an elevation of 1.8 m were noted. The average elevation of the contour is in the order of 1.3 m. Hurricane Maria eroded the beach and vegetation up to an average elevation of 1.6 m and moved the contour inland approximately 3.2 m. Aerial photos after Hurricane Maria did not show significant changes inland beyond the contour.
Shoreline Position	The range of shoreline positions varied gradually from 5.3 m at the eastern end to 2.4 m at the western end. At transects 3 and 4 there is a rock outcrop which is intermittently covered by sand and which affects the estimation of the shoreline position. At the headland (transect 6) the shoreline position ranged approximately 10 m. After Hurricane Maria, the shoreline position remained within the range of shoreline positions during the BDI.
Surface Water Runoff	No beach-wide impact. However, during the extreme rainfall event of November 2016 surface water runoff breached the beach berm near transect 1 (see **Figure 5-11**). Rainfall during Hurricane Maria flooded Laguna Puerto Diablo to the south and excess water flowed to the beach, across the access road, breaching the berm at transect 5 (see **Figure 5-41**). Only localized beach changes were observed.
Sediment	The size of the backshore sediment is not uniform and varies between 0.21 and 0.27 mm (fine to medium sand). At the shoreline, the sediment size is not uniform and varies between 0.20 and 1.10 mm (fine to very coarse sand). The size of the nearshore sediment also shows a large variability, in the range of 0.23 to 0.44 mm (fine to medium sand). The gradation of the sediment appears random, and likely responds to the absence of wave-induced sorting due to the small waves at this beach.
Wave Conditions	Typical between 0.5 to 1 m, 5 to 7 seconds, up to 11 seconds, from the east and northeast. The estimated maximum significant wave height during Hurricane Maria was 1.5 m, 9-second peak period from the northeast.
Wind Conditions	Typical 10 to 15 knots from the east, up to 20 knots. Occasionally from the north.

TABLE 5-10
Beach Dynamics Analysis for Beach 22 (west) (Puerto Diablo, UXO 7)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

	Analysis
Dynamics	Due to the wave protection offered by the rocky headlands and reefs at each side, which form narrow channels where the predominant refracted waves from the northeast refract and break this beach is stable.
Beach Profiles	Most profiles showed small changes in the nearshore, except at transects 9 and 10 where changes in elevation of nearly 1 m were noted. The average maximum elevation change of the beach profiles was approximately 1 m, close to the shoreline at the ends of the beach and landwards of the shoreline at the center between transects 8 and 9. In the backshore at transect 7 the shoreline position showed changes in the order of 10 m, and changes in elevation were approximately 1.5 m. No other transects showed similar changes. No significant erosion or accretion of sediment was noted along the shoreline and landwards after Hurricane Maria, but some accretion was noted in the nearshore possibly from onshore transport.
Area of Beach Change	The width of the area of beach change varied between 100 and 111 m. The widest area is at the western end of the beach.
Depth of Closure	The contour is parallel to the shoreline. Its determination was difficult due to the relatively small bottom changes at some transects, the presence of a sand channel and reefs, and the inherent resolution and repeatability limitations of the surveys. The estimated depth of closure ranges between -2.9 and -3.5 m.
Landward Limit of Beach Change	The contour is uniform and parallel to the shoreline bordering the vegetation line. Changes up to an elevation of 1.6 m were noted. The average elevation of the contour was 1.4 m. Hurricane Maria eroded the beach and vegetation up to an average elevation of 2.2 m and moved the contour inland approximately 4.9 m. Aerial photos after Hurricane Maria did not show changes inland beyond the contour.
Shoreline Position	The range of shoreline positions varied gradually from 8 m at the eastern end to 2.3 m at the western end. After Hurricane Maria, the shoreline remained within the range of shoreline positions during the BDI.
Surface Water Runoff	No beach-wide impact. However, rainfall during Hurricane Maria flooded a low land area just south at transect 7, and surface water runoff breached the beach berm (see **Figure 5-42**). Only localized beach changes were observed.
Sediment	The size of the backshore sediment is not uniform and varies between 0.42 and 0.52 mm (medium to coarse sand). At the shoreline, the sediment size is not uniform and varies between 0.67 and 1.13 mm (coarse to very coarse sand). The size of the nearshore sediment is uniform and in the range of 0.30 to 0.42 mm (medium sand). The gradation of the sediment appears random, and likely responds to the absence of wave-induced sorting due to the small waves at this beach.
Wave Conditions	Typical between 0.5 to 1 m, 5 to 7 seconds, up to 11 seconds, from the east and northeast. The estimated maximum significant wave height during Hurricane Maria was 1.5 m, 9-second peak period from the northeast.
Wind Conditions	Typical 10 to 15 knots from the east, up to 20 knots. Occasionally from the north.

TABLE 5-11
Beach Dynamics Analysis for Beach 24 (Purple Beach/Playa Campaña**, UXO 7)**
Beach Dynamics Investigation Report
Vieques, Puerto Rico

	Analysis
Dynamics	This beach is dynamic and the most dynamic of all the BDI beaches on the north coast due to its exposure to northeast waves during the winter. The 2-m deep fringing reef fronting the beach is insufficient to fully protect the beach.
Beach Profiles	The average maximum elevation change of the beach profiles was approximately 2.5 m. Changes were confined to an area from the vegetation line to the -1 m water depth. Most profiles showed relatively small changes beyond the -1 m water depth, except for transects 1, 2, 4, 7 and 8 where changes of approximately 0.5 m were noted. All bottom slopes are gentle and uniform along the beach, except at transect 1 where a dip is noted. The fringing reef works like the sill of a perched beach which contains sediment in the nearshore. No significant erosion or accretion of sediment was noted in the nearshore after Hurricane Maria.
Area of Beach Change	The width of the area of beach change varies along most of the beach between approximately 23 and 120 m, except at transect 8 where a sand channel is located, resulting in bottom changes further offshore to approximately 230 m from the shoreline.
Depth of Closure	The contour approximately follows the fringing reef. Depths of closure are relatively shallow and in the -1 to -2 m range, except at transect 8 where the depth of closure is -4.3 m due to the presence of the sand channel; and at transect 5 where a rock outcrop surfaces at -0.45 m water depth.
Landward Limit of Beach Change	The contour is approximately parallel to the shoreline reaching further inland and into the vegetation at the ends of the beach. No significant changes in elevation were noted and the average elevation was 1.8 m. Hurricane Maria eroded the beach and vegetation up to an average elevation of about 1.9 m and moved the contour inland approximately 1.6 m. Aerial photos after Hurricane Maria did not show changes inland beyond the contour.
Shoreline Position	In general, shoreline positions varied significantly, particularly at the ends of the beach suggesting a longshore transport of sediment. Changes were in the order of 20 m at the eastern end and 57 m at the western end. The inspection of historical shoreline positions showed that changes were cyclical, with a peak advance of the shoreline at the western end at the end of the summer in September and associated with the easterly wave climate, and a retreat peaking in April/May after the winter associated with northeasterly waves. At transect 5 there is a location where the range of shoreline change was small (approximately 13 m) due to the presence of a rock outcrop at the shoreline. After Hurricane Maria, the shoreline remained within the range of shoreline positions during the BDI.
Surface Water Runoff	No beach-wide impact. However, during the extreme rainfall event of November 2016 the ephemeral creek at the west end breached the beach berm between transects 8 and 9 (see **Figure 5-10**). Rainfall during Hurricane Maria caused the creek to breach the beach berm again at the same location. In both cases only localized beach changes were observed.
Sediment	The size of the backshore sediment is uniform and varies between 0.29 and 0.36 mm (medium sand). The size of the shoreline sediment is not uniform and varies between 0.34 and 0.57 mm (medium to coarse sand). The size of the nearshore sediment is uniform between 0.17 and 0.19 mm (fine sand). The gradation of the sediment from relatively coarse on the beach to fine in the nearshore is typical.
Wave Conditions	Typical between 0.6 and 1.2 m, 5 to 7 seconds, occasionally 10 seconds, from the east-northeast. The estimated maximum significant wave height during Hurricane Maria was 1.5 m, 9-second peak period from the northeast.
Wind Conditions	Typical 10 to 15 knots from the east, occasionally 20 knots.

TABLE 5-12
Beach Dynamics **Analysis for Beach 1 (Yellow Beach/Playa Matías, UXO 8)**
Beach Dynamics Investigation Report
Vieques, Puerto Rico

	Analysis
Dynamics	This beach is dynamic and the most dynamic of all the BDI beaches on the south coast due to its exposure to the predominant refracted waves from the southeast, storm waves from the south, and because it is not protected by islands or reefs.
Beach Profiles	The average maximum elevation change of the beach profiles was approximately 1.7 m, mostly along the shoreline, except at transect 8. At transect 8, the vegetation line is discontinued by a rock bluff which may have caused the maximum elevation change of the profile at that location to be seaward of the shoreline. The maximum elevation change of the beach profiles increased from 1.6 m at transect 1 to 2 m at transect 6. Along the beach, the bottom slopes appear even, except at the eastern end where they are shallower, likely due to the supply of sediment from the ephemeral creek that conveys rainfall collected in the watershed to the east of Cerro Matias Jalobre. Hurricane Maria moved large amounts of sediment, likely and predominantly from the beach to the nearshore up to and beyond the depth of closure, but possibly also from offshore.
Area of Beach Change	The width of the area of beach change varied between 111 and 149 m. The widest areas were at the ends of the beach and the narrowest at the center at transect 7.
Depth of Closure	The contour is approximately parallel to the shoreline, diverging seaward east of transect 7. Depths of closure are relatively deep, suggesting high waves at this beach, which is consistent with observations. Depths of closure decrease gradually from the western to the eastern end, from nearly -6 to -3.6 m, suggesting that wave heights on the western end are typically higher than on the eastern end and/or larger grain size at the eastern end from a supply of sediment from the ephemeral creek that conveys rainfall collected in the watershed to the east of Cerro Matias Jalobre.
Landward Limit of Beach Change	The contour is uniform and approximately parallel to the shoreline reaching further inland and into the vegetation at the eastern end, likely due to the gentler bottom slopes at the eastern end which allow wave runup further inland. No significant changes in elevation were noted and the average elevation was 1.6 m. Hurricane Maria eroded the beach and vegetation up to an elevation of 2.3 m and moved the contour inland approximately 22 m. This significant landward erosion exposed concrete blocks, previously used for training, that were buried under the sand between transects 5 and 7 (see **Figure 5-43**). Aerial photos after Hurricane Maria showed changes inland beyond the contour, but these are attributed to transport of sand and erosion of vegetation by wind.
Shoreline Position	Shoreline positions varied uniformly along the beach suggesting a dominant cross-shore transport of sediment. The range of shoreline position change was approximately uniform and ranged between 16 and 23 m. After Hurricane Maria, the maximum shoreline retreat peaked at 20 m beyond the extreme during the BDI at the west end at transect 1 to gradually decrease to the east where, at transect 6 and beyond, the shoreline retreat was comparable to that due to Tropical Storm Erika and Hurricane Matthew. The inspection of beach profiles before and after these storms showed that the shoreline retreat corresponded with the accretion of sediment in the nearshore, suggesting that cross-shore was the dominant transport direction during these storms.
Surface Water Runoff	No beach-wide impact. The extreme rainfall event of November 2016, and Hurricane Maria, caused the ephemeral creek at transect 9 to breach the beach berm (see **Figure 5-8** and **Figure 5-9**) and deposit sediment in the nearshore, mainly at transect 9 and decreasing to the east up to transect 7.

TABLE 5-12
Beach Dynamics **Analysis for Beach 1 (Yellow Beach/Playa Matías, UXO 8)**
Beach Dynamics Investigation Report
Vieques, Puerto Rico

	Analysis
Sediment	The size of the backshore sediment is not uniform and varies between 0.17 and 0.42 mm (fine to medium sand) likely due to mixing generated by storms. The size of the shoreline sediment is more uniform and varies between 0.27 and 0.42 mm (medium sand). The size of the nearshore sediment is uniform between 0.18 and 0.22 mm (fine sand). The gradation of the sediment from relatively coarse on the beach to fine in the nearshore is typical.
Wave Conditions	Typical between 0.5 to 1 m, up to 1.5 m, 5 to 7 seconds, occasionally 11 seconds, from the east-southeast. The estimated maximum significant wave height during Hurricane Maria was 2 to 3 m, 14-second peak period from the southeast.
Wind Conditions	Typical 10 to 15 knots from the east-southeast, occasionally 20 knots. The wind direction in the winter is from the north.

TABLE 5-13
Beach Dynamics Analysis for **Beach 19 (Playa Yoyé, UXO 8)**
Beach Dynamics Investigation Report
Vieques, Puerto Rico

	Analysis
Dynamics	Due to the wave protection offered by two long rocky headlands and reefs at each side that form a narrow channel where waves refract and break this beach is stable.
Beach Profiles	Beach profiles showed negligible changes. The average maximum elevation change of the beach profiles was approximately 0.4 m, generally landwards of the shoreline. The small changes in elevation are likely due to the small waves at this beach, but also due to the large seagrass patches that front the beach and can introduce variability in the soundings. The bottom slopes are similar along the beach. No significant erosion or accretion of sediment was noted after Hurricane Maria, except at approximately 100 m from the shoreline where a depression on the bottom acts as a sediment trap.
Area of Beach Change	The width of the area of beach change varies between 27 and 45 m, which is wide for the relatively small waves at this beach. The changes in bottom elevation in the nearshore are small and in the order of 0.1 m, which makes it challenging to identify the depth of closure.
Depth of Closure	Given the small change in the bottom elevation in the nearshore, the location of the depth of closure was difficult to identify and includes uncertainty. Actual changes in the profiles are of a similar magnitude given the potential differences introduced by the inherent resolution and repeatability limitations of the surveys, including the variability due to surveying over seagrass. For the small waves at this beach, the depth of closure ranging between -0.9 and -1.6 m is deeper than anticipated.
Landward Limit of Beach Change	The contour is uniform and parallel to the shoreline away from the vegetation line. No significant changes in elevation were noted and the average elevation is 0.9 m. Hurricane Maria eroded the beach and vegetation up to an elevation of 2 m and moved the contour inland approximately 10 m. Aerial photos after Hurricane Maria showed changes inland beyond the contour, but these are attributed to transport of sand and erosion of vegetation by wind.
Shoreline Position	Shoreline positions varied uniformly along the beach and in a narrow 1.6 to 2.4 m range suggesting negligible beach changes. No retreat of the shoreline occurred after Tropical Storm Erika and Hurricane Matthew. After Hurricane Maria, the shoreline did not retreat on the western end of the beach between transects 1 and 2, but gradually moved seaward towards the eastern end from transect 2 to 5, suggesting beach accretion in that area of the beach.
Surface Water Runoff	No impact.
Sediment	The size of the backshore sediment is uniform and varies between 0.27 and 0.38 mm (medium sand), and is finer than the shoreline sediment which is also uniform and in the range of 0.78 to 0.88 mm (coarse sand). An outlier of nominal diameter 0.36 mm is noted in the shoreline for the second sample. The size of the nearshore sediment is not uniform and varies between 0.41 and 1.10 mm (medium to very coarse sand). The gradation of the sediment from relatively fine on the beach to coarse in the nearshore is not typical and likely results from different processes and conditions (waves, seagrass, sediment supply) present at the backshore and shoreline, and at the nearshore.
Wave Conditions	Typical less than 0.5 m, 5 to 7 seconds from the southeast. The estimated maximum significant wave height during Hurricane Maria in the nearshore was 2 m, 14-second peak period from the southeast.
Wind Conditions	Typical 15 knots from the east.

TABLE 5-14
Beach Dynamics Analysis for Beach SWMU 4 (southwest-facing) (Unnamed)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

	Analysis
Dynamics	Due to the wave protection offered by the shallow reefs and the orientation of the beach relative to the predominant easterly waves this beach is stable.
Beach Profiles	Beach profiles showed negligible changes. The average maximum elevation change of the beach profiles was approximately 0.7 m landward of the shoreline. On some transects, changes in elevation of approximately 0.5 m were noted in the nearshore likely due to the very uneven bathymetry of the of reefs fronting the beach and difficulty of surveying repeatedly exactly on the transect. The headland, Punta Boca Quebrada (transect 13), is dynamic. At the eastern end at transect 1 maximum elevation change of about 1.6 m was noted landwards of the shoreline. At the headland, the shoreline position showed changes in the order of 10 m, and 1 m in elevation. The headland is a very complex feature where waves run on a reef and break on the shore from different directions and this results in changes that are not representative of the rest of the beach. No significant erosion or accretion of sediment was noted after Hurricane Maria, except for accretion at approximately 70 m beyond the shoreline and, particularly, near transects 1, 2, and 3 where the creek in the OB/OD area flows to the sea.
Area of Beach Change	The width of the area of beach change is very variable, between 22 to 52 m. This reflects the uncertainty in the determination of the depth of closure due to the presence of reefs.
Depth of Closure	The depth of closure contour is irregular and reflects the difficulty in identifying its location accurately due to the inherent resolution and repeatability limitations of the surveys, the relatively small bottom changes, and the presence of the reefs. The estimated depth of closure ranges between -1.2 and -2.9 m.
Landward Limit of Beach Change	The contour is parallel to the shoreline bordering the vegetation line. Changes in elevation are noted. At the southeast end of the beach, where the creek in the OB/OD area flows to the sea, the elevation at 0.3 m is the lowest. The contour shows variable elevations from one end of the beach to the other, between 0.3 and 1.6 m. The average elevation of the contour is approximately 1.2 m. Hurricane Maria did not erode the beach significantly, except at Punta Boca Quebrada which was completely eroded down to the rock substrate. Aerial photos after Hurricane Maria showed changes inland beyond the contour, but these are attributed to transport of sand and erosion of vegetation by wind.
Shoreline Position	Shoreline positions did not show any particular trend other than generally varying in a narrow 2 to 4 m range, because the shallow reefs fronting the beach offer wave protection. At transect 6 and 13 (Punta Boca Quebrada) changes of 7 and 9.4 m were noted, respectively, likely due to localized wave effects. At the headland (transect 13) this would be the case since headlands area has complex features where waves run on shoals and break on the shore from different directions. After Hurricane Maria, the shoreline remained within the range of shoreline positions during the BDI.
Surface Water Runoff	No beach-wide impact. No observations were performed after the extreme rainfall event of November 2016. Hurricane Maria caused the ephemeral creek at transect 1 to breach the beach berm (see **Figure 5-44**) and deposit sediment in the nearshore, near transects 1, 2, and 3.
Sediment	The size of the backshore sediment is not uniform and varies significantly between 0.56 and 2.40 mm (coarse sand to very fine pebbles). At the shoreline, the sediment size is not uniform and even coarser, it varies between 2.00 and 5.77 mm (very coarse sand to fine pebbles). The nearshore sediment is finer but also shows a large variability, in the range of 0.16 to 0.32 mm (fine to medium sand). The gradation of the sediment appears random, and likely responds to the absence of wave-induced sorting due to the small waves.

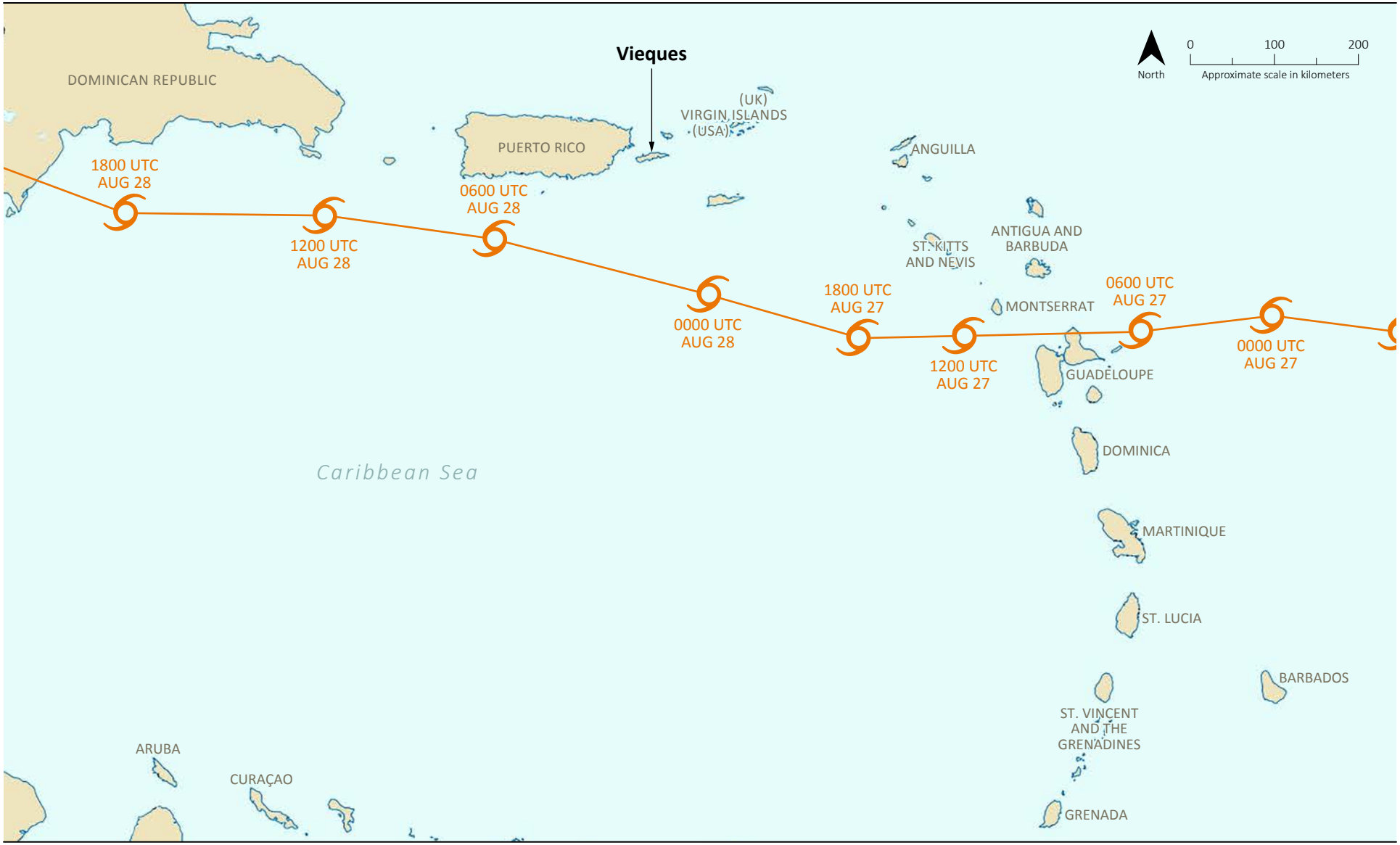
TABLE 5-14
Beach Dynamics Analysis for Beach SWMU 4 (southwest-facing) (Unnamed)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

	Analysis
Wave Conditions	Typical less than 0.5 m, occasionally 1 m, 5 to 7 seconds waves, up to 10 seconds, from the south. The estimated maximum significant wave height during Hurricane Maria was 2 m, 13-second peak period from the southwest.
Wind Conditions	Typical 5 to 15 knots from the east to south, up to 20 knots. Occasionally from the northeast.

TABLE 5-15
Beach Dynamics Analysis for Beach SWMU 4 (west-facing) (Unnamed)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

	Analysis
Dynamics	Due to the wave protection offered by the shallow reefs and the orientation of the beach relative to the predominant easterly waves this beach is stable.
Beach Profiles	Beach profiles showed negligible changes. The average maximum elevation change of the beach profiles was approximately 0.6 m landward of the shoreline. On some transects, changes in elevation of approximately 0.5 m were noted in the nearshore likely due to the very uneven bathymetry of the of reefs fronting the beach and difficulty of surveying repeatedly exactly on the transect. No significant erosion or accretion of sediment was noted after Hurricane Maria, except for accretion at approximately beyond 70 m from the shoreline.
Area of Beach Change	The width of the area of beach change is very variable, between 22 to 49 m. This reflects the uncertainty in the determination of the depth of closure due to the presence of reefs.
Depth of Closure	The depth of closure contour is irregular and reflects the difficulty in identifying its location accurately due to the inherent resolution and repeatability limitations of the surveys, the relatively small bottom changes, and the presence of the reefs. The estimated depth of closure ranges between -1 and -1.7 m.
Landward Limit of Beach Change	The contour is parallel to the shoreline reaching further inland and into the vegetation line. The elevation varies between 0.7 and 1.2 m. The average elevation of the contour is about 0.9 m. Hurricane Maria did not erode the beach significantly. Aerial photos after Hurricane Maria showed changes inland beyond the contour, but these are attributed to transport of sand and erosion of vegetation by wind.
Shoreline Position	Shoreline positions did not show any particular trend, and ranges decreased from south to north from a maximum of approximately 5 m at transect 14 to a minimum of 1 m at transect 17. After Hurricane Maria, the shoreline just north of Punta Boca Quebrada did not retreat and remained within the range of shoreline positions during the BDI. For the stretch north of the Laguna Boca Quebrada inlet the shoreline moved to an extreme seaward location, approximately 5 m seaward from its most seaward location during the BDI.
Surface Water Runoff	No beach-wide impact. No observations were performed after the extreme rainfall event of November 2016. Sediment flowing to the sea from the Laguna Boca Quebrada during Hurricane Maria, combined with longshore sediment from the south, completely blocked the culvert connecting the lagoon to the sea, and covered the road bridge (see **Figure 5-45**). A significant accretion of sediment was observed at that location.
Sediment	The size of the backshore sediment is not uniform and varies between 0.67 and 1.75 mm (coarse to very coarse sand). At the shoreline, the sediment size is uniform and varies between 1.01 and 1.66 mm (very coarse sand). The size of the nearshore sediment is uniform and very fine, nearly 80 percent of the sediment is finer than 0.1 mm (very fine sand). An outlier of nominal diameter 0.26 mm is noted in the shoreline for the first sample. The gradation of the sediment appears random, and likely responds to the absence of wave-induced sorting due to the small waves.
Wave Conditions	Typical less than 0.5 m, occasionally 1 m, 5 to 7 seconds, up to 10 seconds, from the south. The estimated maximum significant wave height during Hurricane Maria was 2 m, 13-second peak period from the southwest.
Wind Conditions	Typical 5 to 15 knots from the east to south, up to 20 knots. Occasionally from the northeast.

Aerial source 2017 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image Landsat/Copernicus.



LEGEND

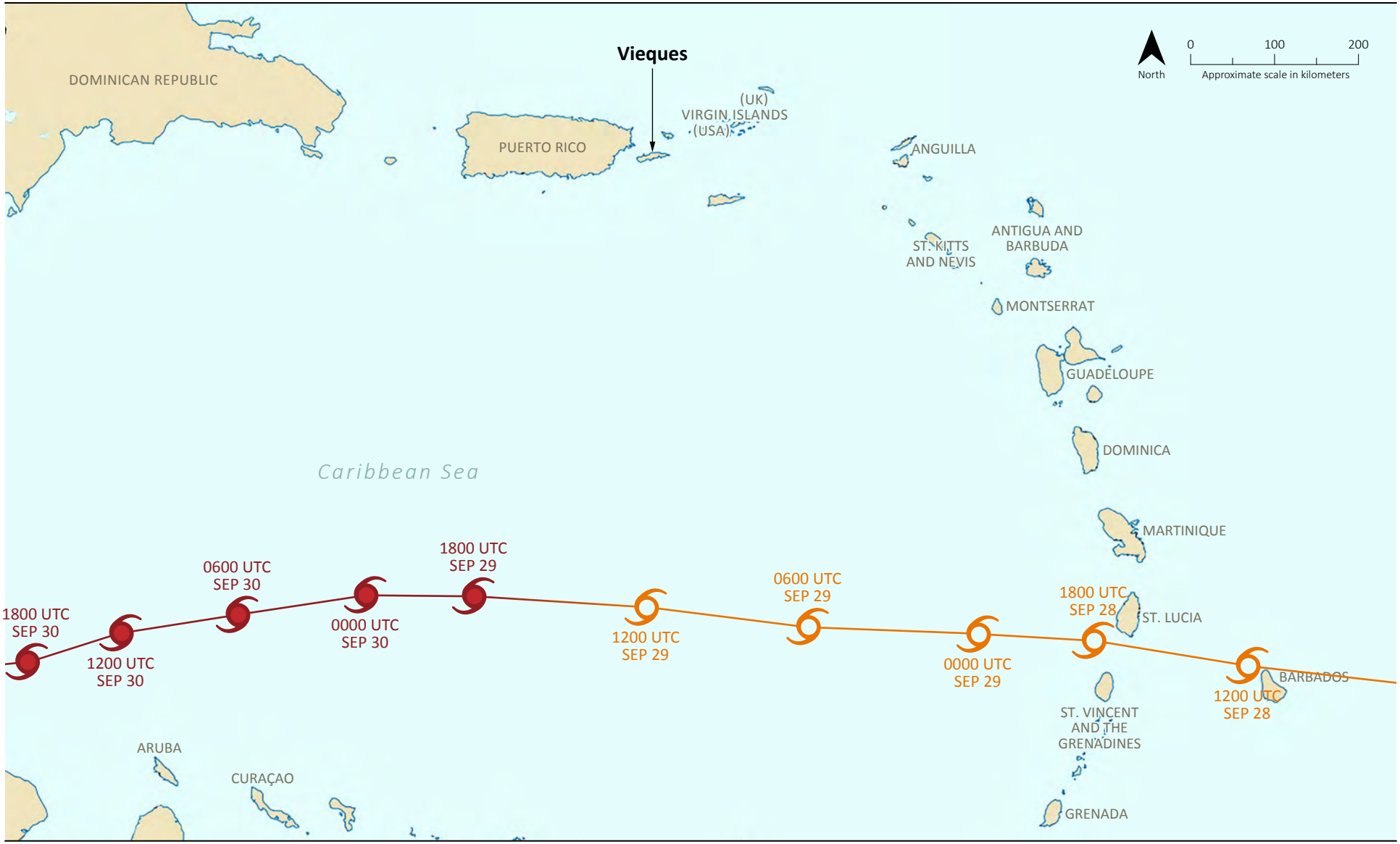
Tropical storm track

Tropical storm location in time

NOTE: UTC = Coordinated Universal Time.

FIGURE 5-1
Tropical Storm Erika Track
(August 2015)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2017 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image Landsat/Copernicus.



LEGEND

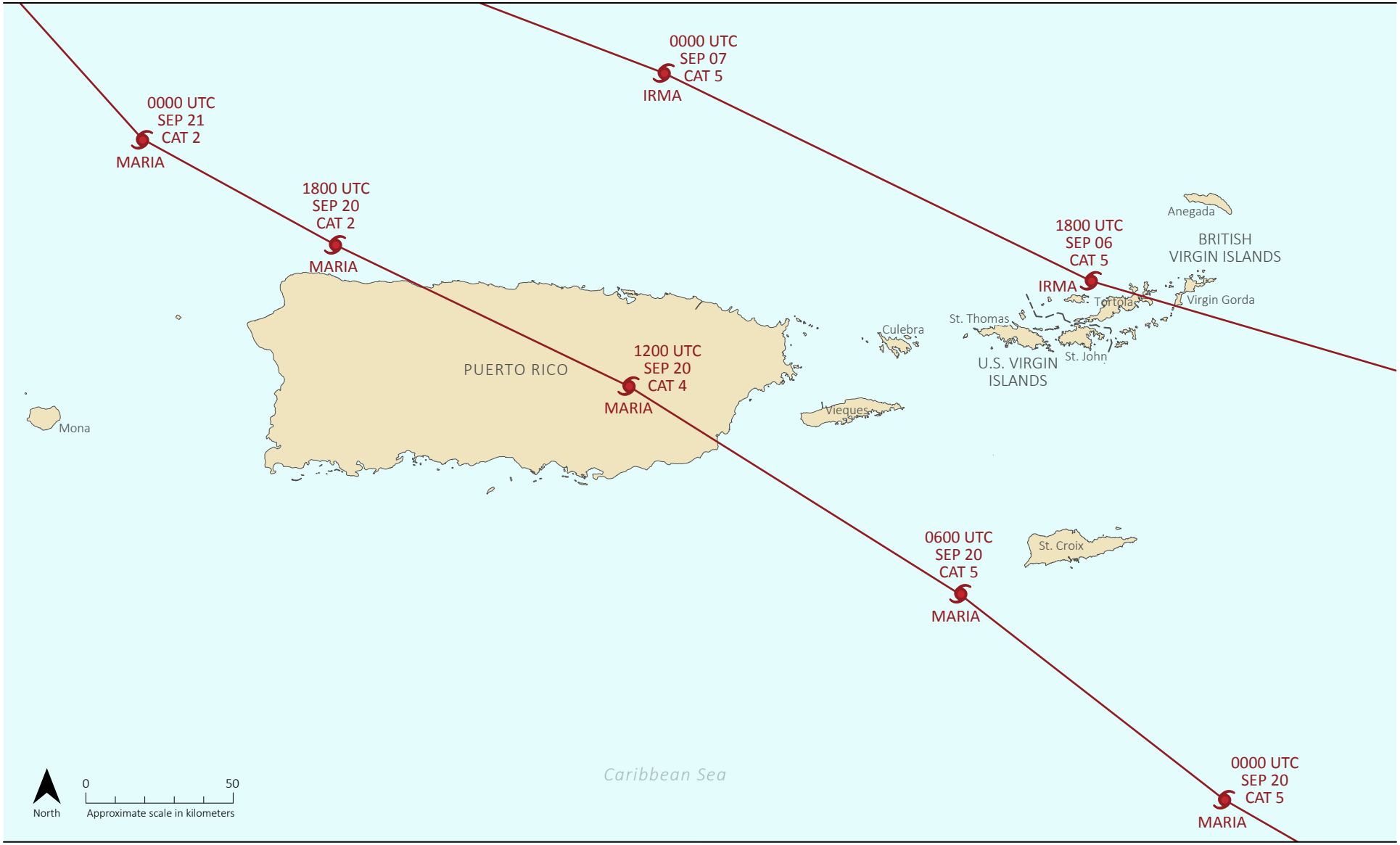
- Hurricane track
- Hurricane location in time (September 2016
- Tropical storm track
- Tropical storm location in time

NOTE: UTC = Coordinated Universal Time.

FIGURE 5-2
Hurricane Matthew Track
(September 2016)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

NG0831170645VBO_r1

Aerial reference image 2018 Google Earth. Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image 2017 Landsat/Copernicus. Data LDEO-Columbia, NSF, NOAA.



LEGEND

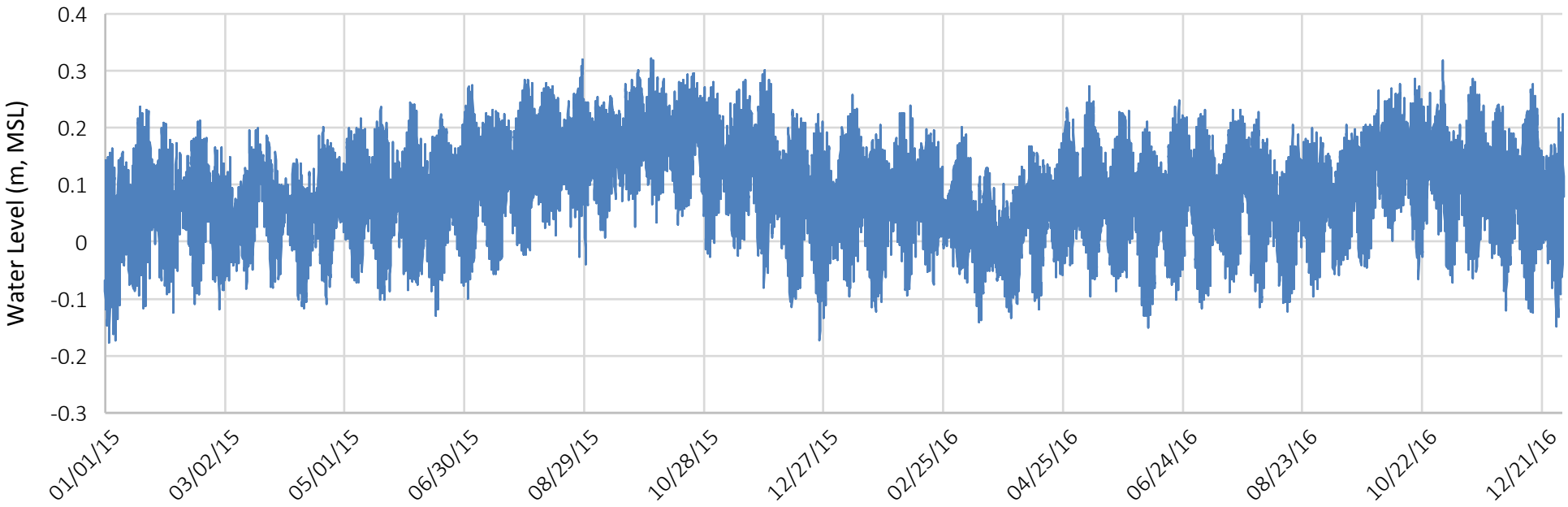
Hurricane track

Hurricane locaton in time

FIGURE 5-3
Hurricane Irma and Maria Tracks
(September 2017)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

NOTE: UTC = Coordinated Universal Time.

NG0831170645VBO



NOTE: MSL = Mean Sea Level.

FIGURE 5-4
Water Levels at NOAA Station 9752695 Esperanza in 2015 and 2016
Beach Dynamics Investigation Report
Vieques, Puerto Rico

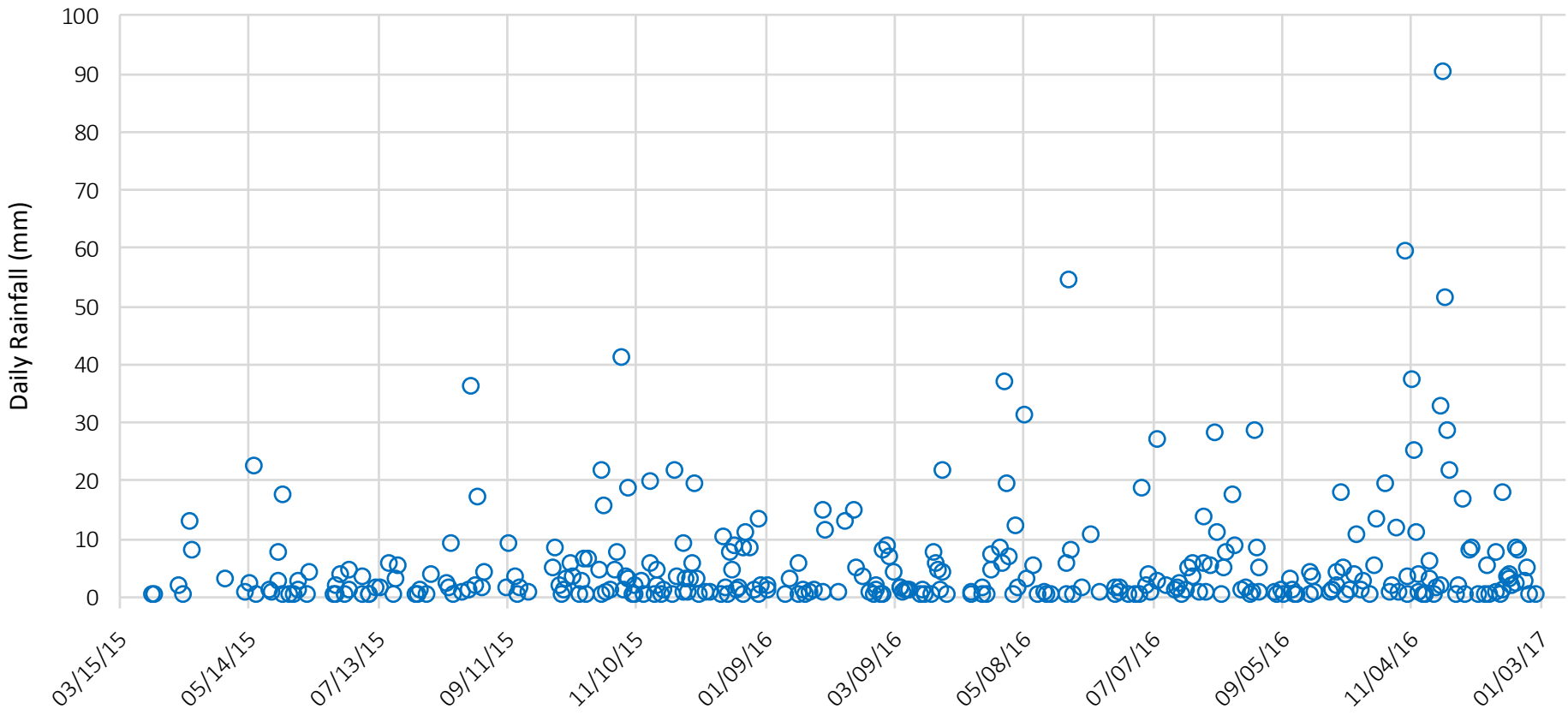
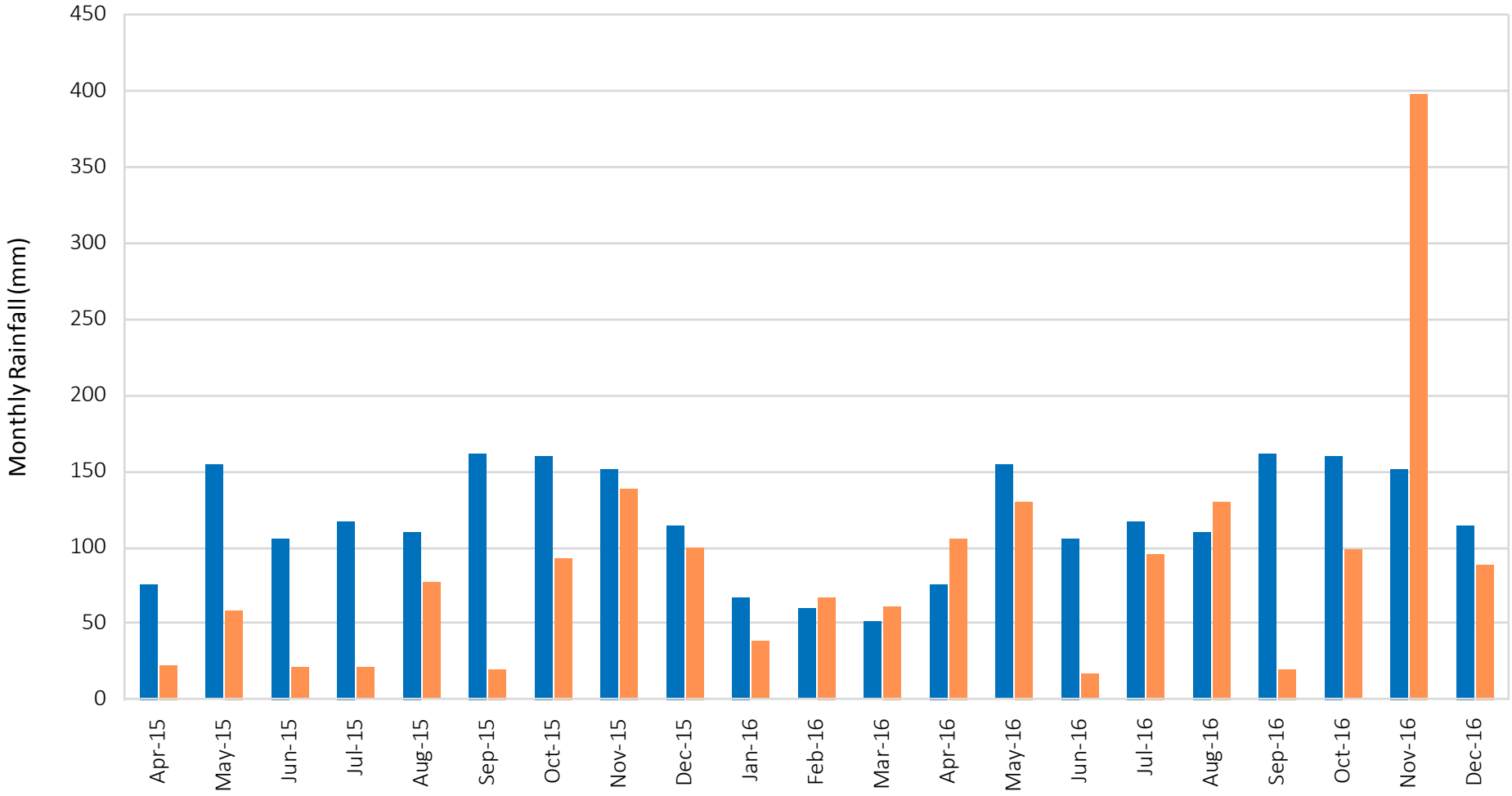


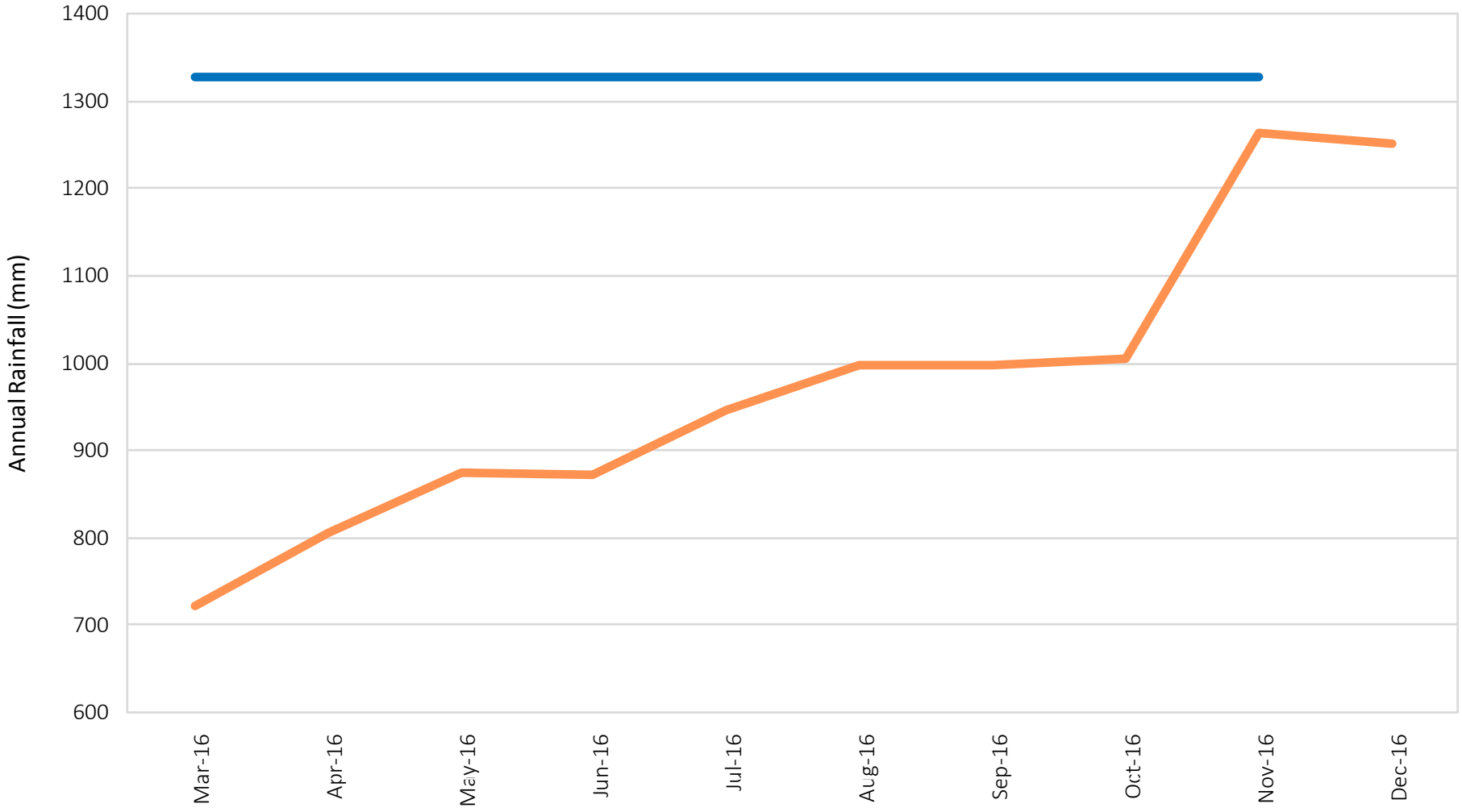
FIGURE 5-5
Daily Rainfall in Vieques during the BDI
Beach Dynamics Investigation Report
Vieques, Puerto Rico



LEGEND

- Roosevelt Roads Average
- Vieques BDI

FIGURE 5-6
Monthly Rainfall in Vieques during the BDI
Beach Dynamics Investigation Report
Vieques, Puerto Rico



LEGEND

Roosevelt Roads Average

Vieques BDI

FIGURE 5-7
Annual Rainfall in Vieques During the BDI
(running total of previous 12 months)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

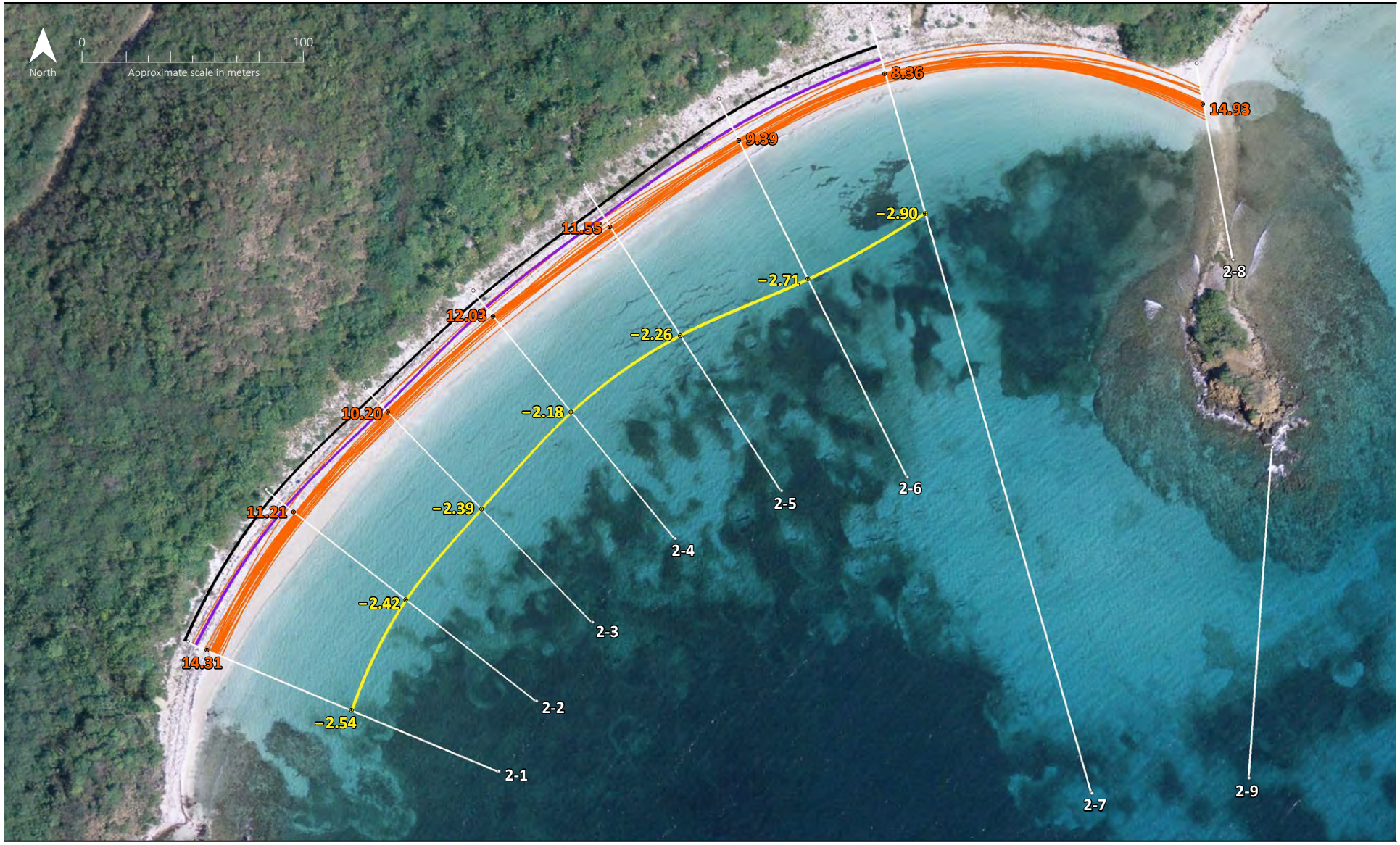
FIGURE 5-8
Ephemeral Stream at the East End of Beach 1 (Transect 9), After the Extreme Rainfall Event of November 2016 (landward view)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

FIGURE 5-9
Ephemeral Stream at the East End of Beach 1 (Transect 9), After the Extreme Rainfall Event of November 2016 (seaward view)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

FIGURE 5-10
Ephemeral Stream at the West End of Beach 24 (between Transects 8 and 9), After the Extreme Rainfall Event of November 2016
Beach Dynamics Investigation Report
Vieques, Puerto Rico

FIGURE 5-11
Surface Water Runoff Breach at Beach 22 (Transect 1), After the Extreme Rainfall Event of November 2016
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.



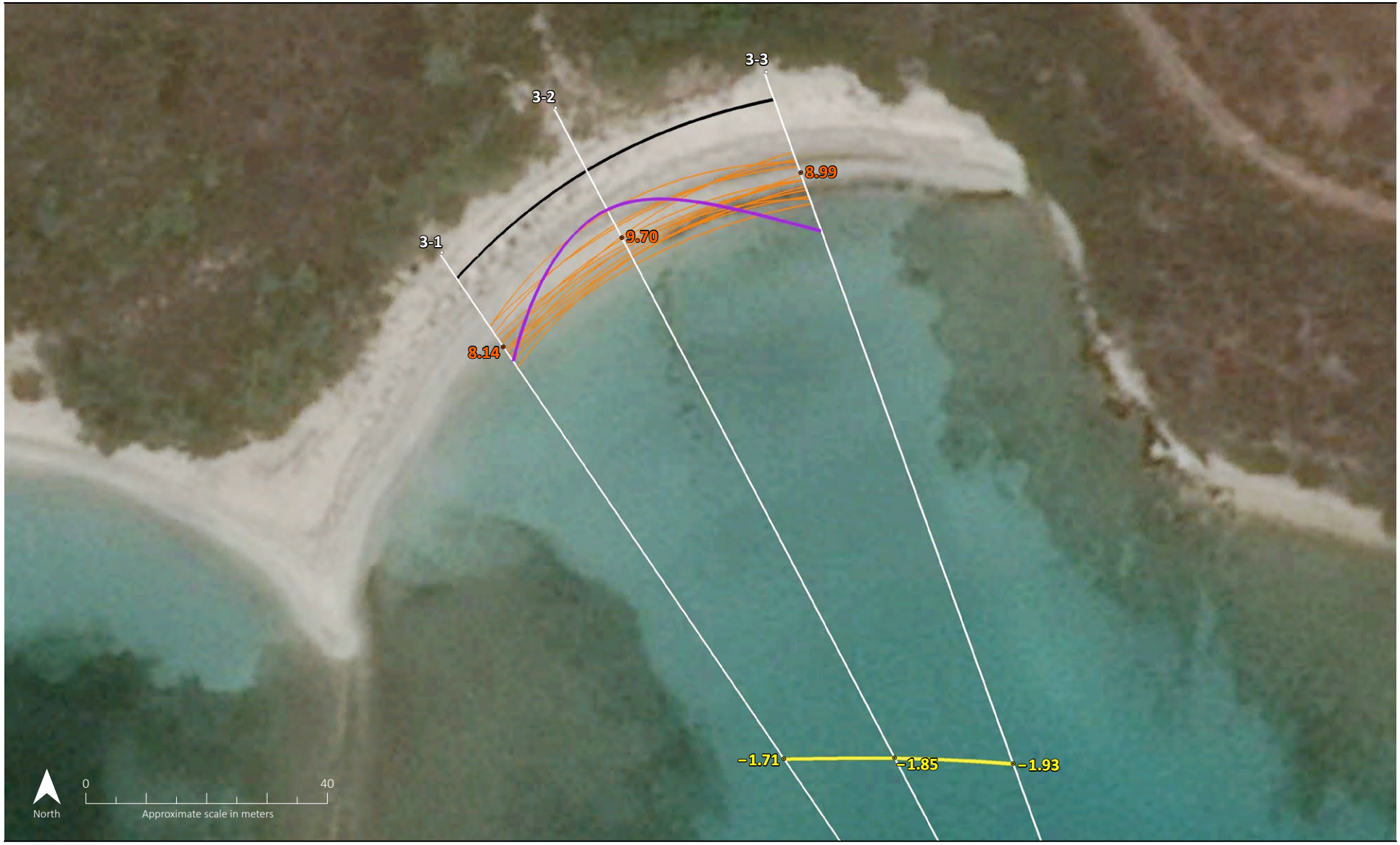
LEGEND

- Depth of closure
- Landward limit of beach change
- Shoreline positions and range of shoreline change
- Maximum beach elevation change

NOTE: All units are meters.

FIGURE 5-12
Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 2
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image © 2018 CNES/Airbus.



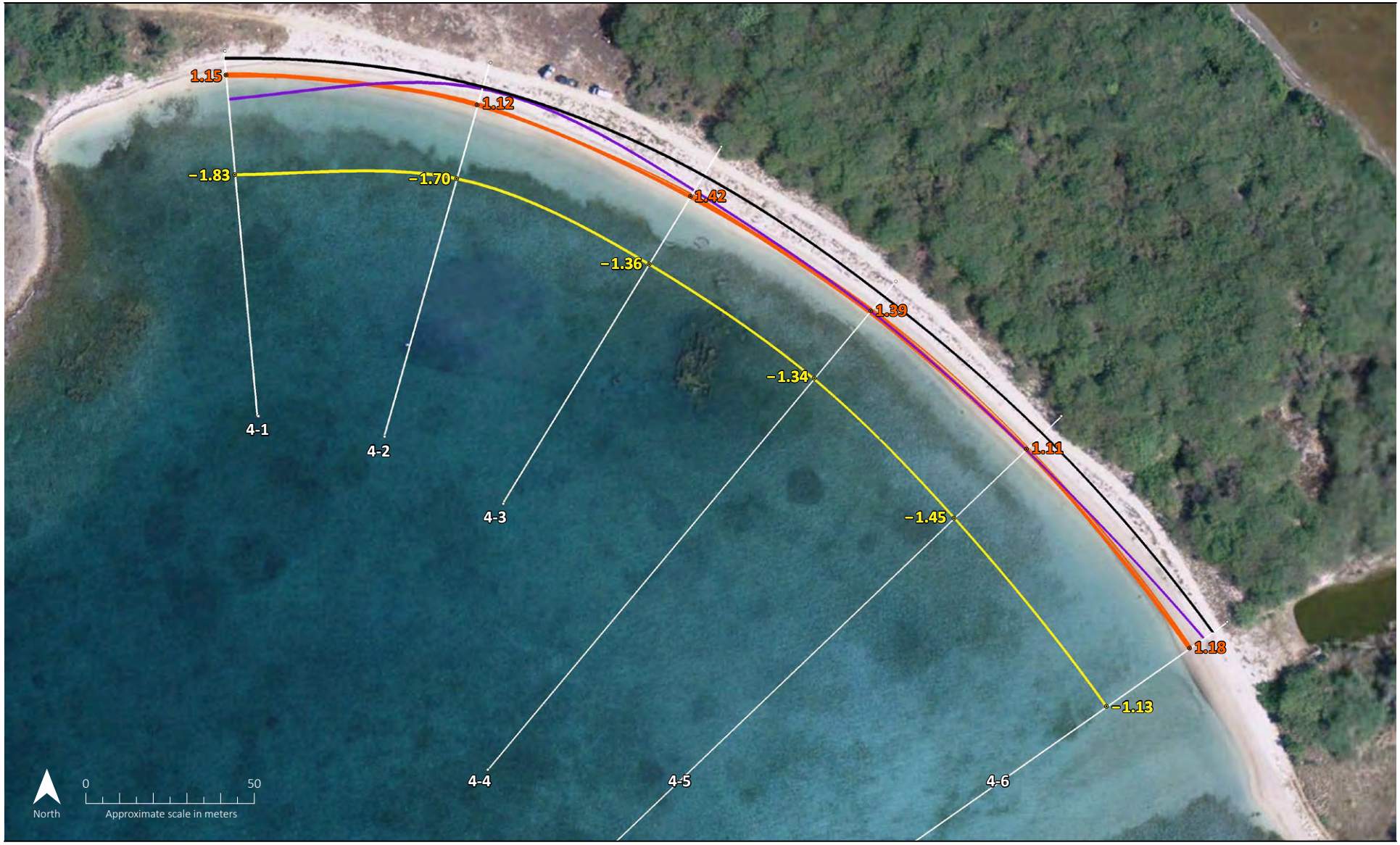
LEGEND

- Depth of closure
- Landward limit of beach change
- Shoreline positions and range of shoreline change
- Maximum beach elevation change

NOTE: All units are meters.

FIGURE 5-13
Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 3
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.



LEGEND

- Depth of closure
- Landward limit of beach change
- Shoreline positions and range of shoreline change
- Maximum beach elevation change

NOTE: All units are meters.

FIGURE 5-14
Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 4
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.

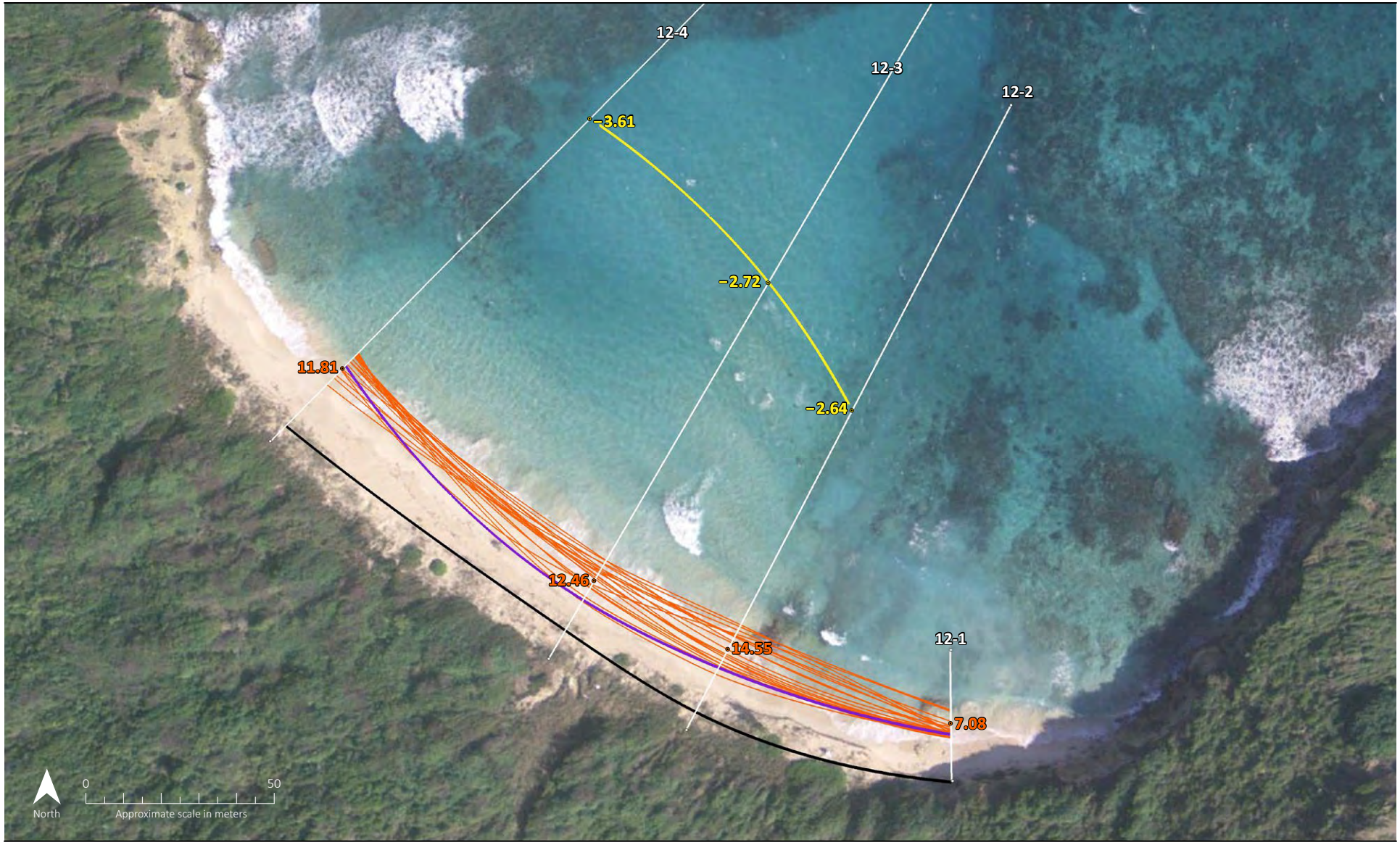
LEGEND

- Depth of closure
- Landward limit of beach change
- Shoreline positions and range of shoreline change
- Maximum beach elevation change

NOTE: All units are meters.

FIGURE 5-15
Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 5
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.



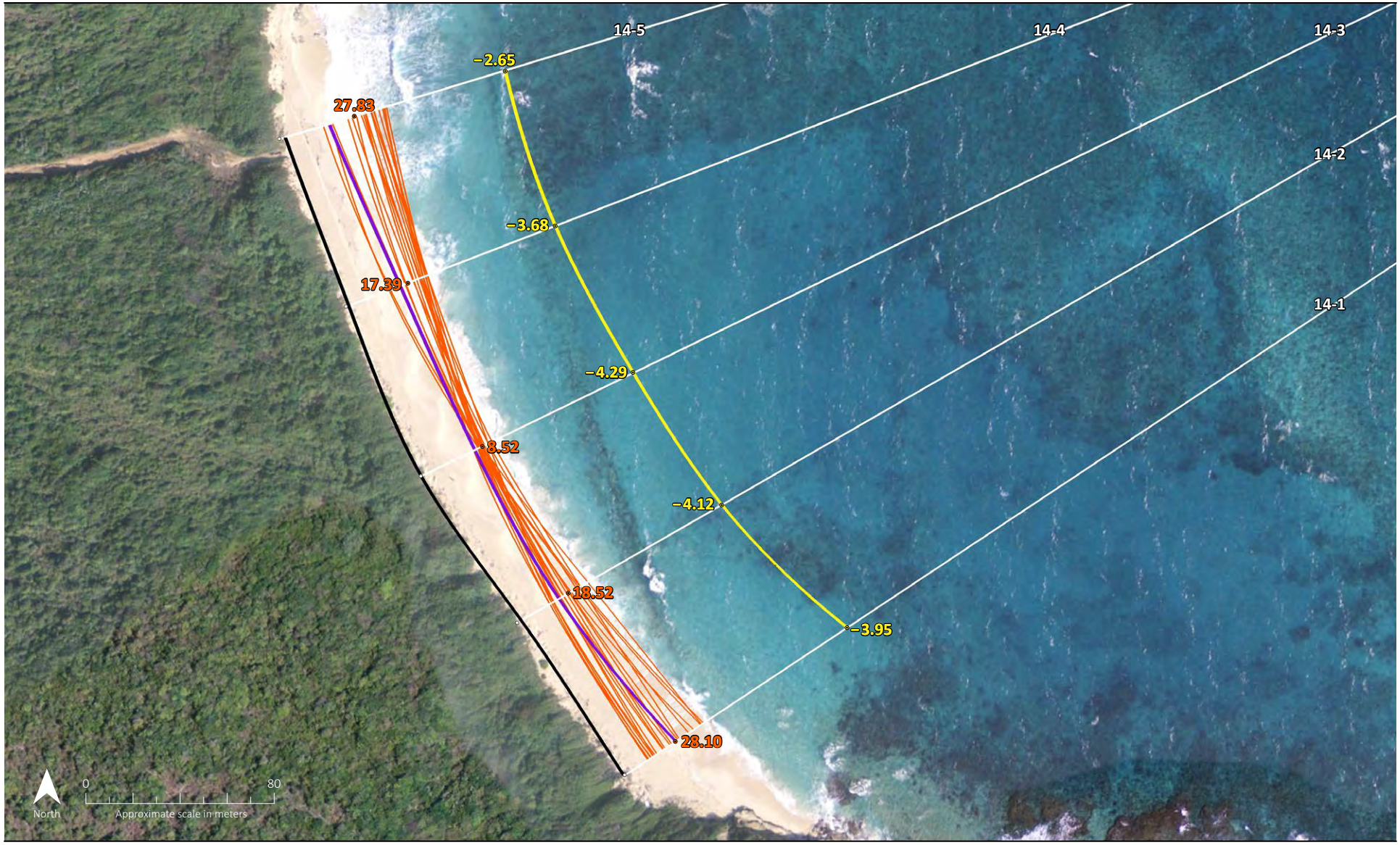
LEGEND

- Depth of closure
- Landward limit of beach change
- Shoreline positions and range of shoreline change
- Maximum beach elevation change

NOTE: All units are meters.

FIGURE 5-16
Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 12
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.



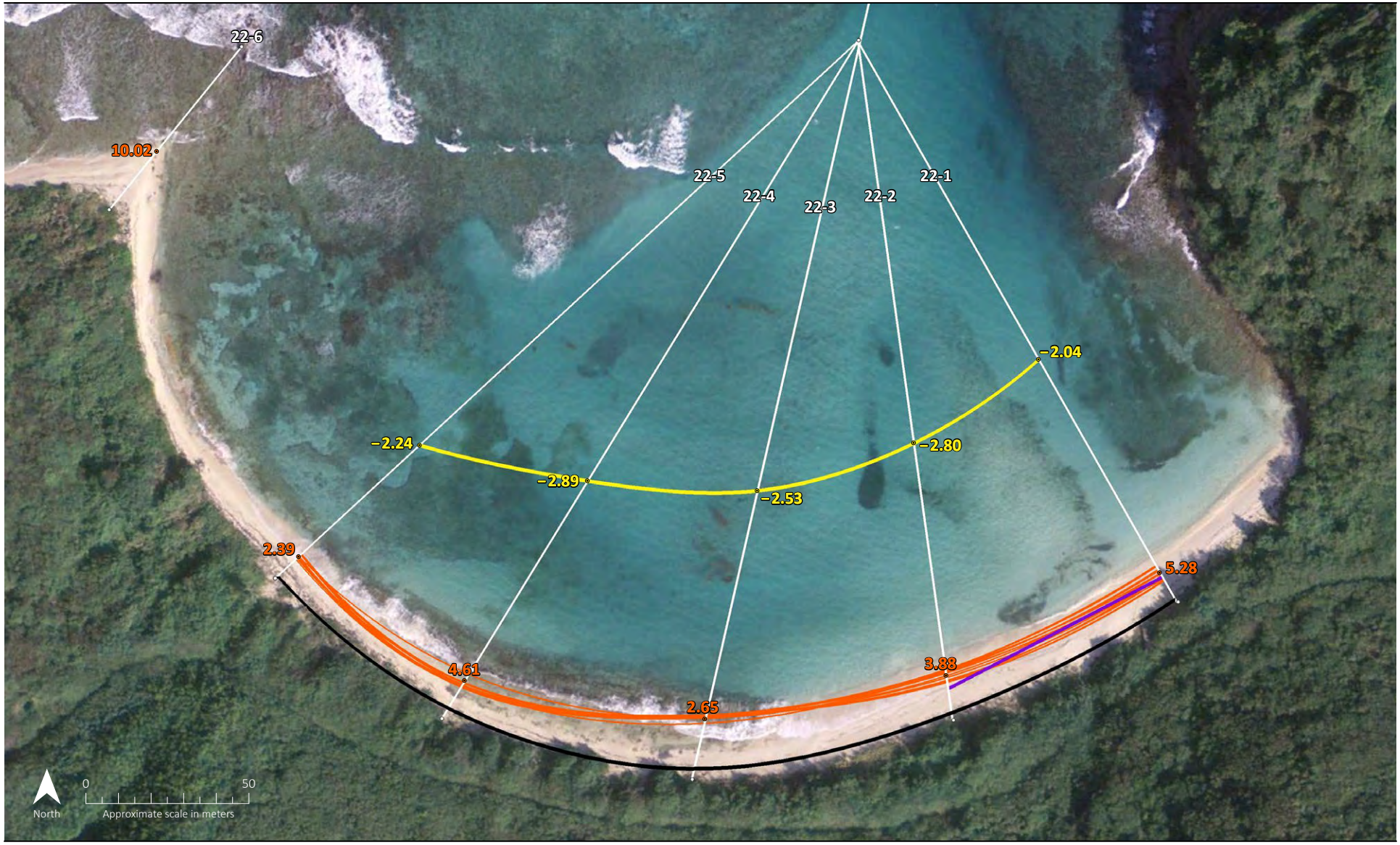
LEGEND

- Depth of closure
- Landward limit of beach change
- Shoreline positions and range of shoreline change
- Maximum beach elevation change

NOTE: All units are meters.

FIGURE 5-17
Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 14
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.



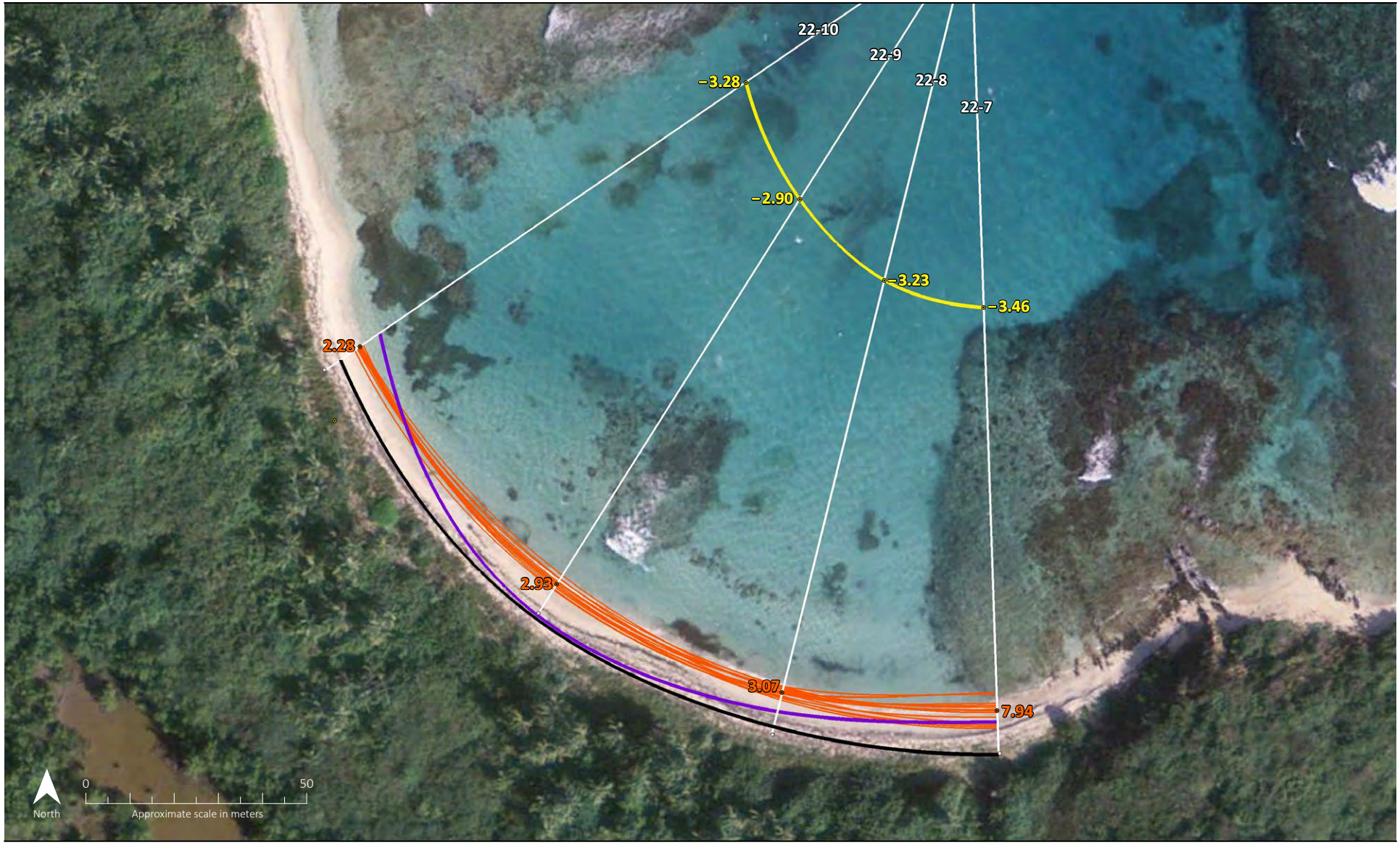
LEGEND

- Depth of closure
- Landward limit of beach change
- Shoreline positions and range of shoreline change
- Maximum beach elevation change

NOTE: All units are meters.

FIGURE 5-18
Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 22 (east)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.



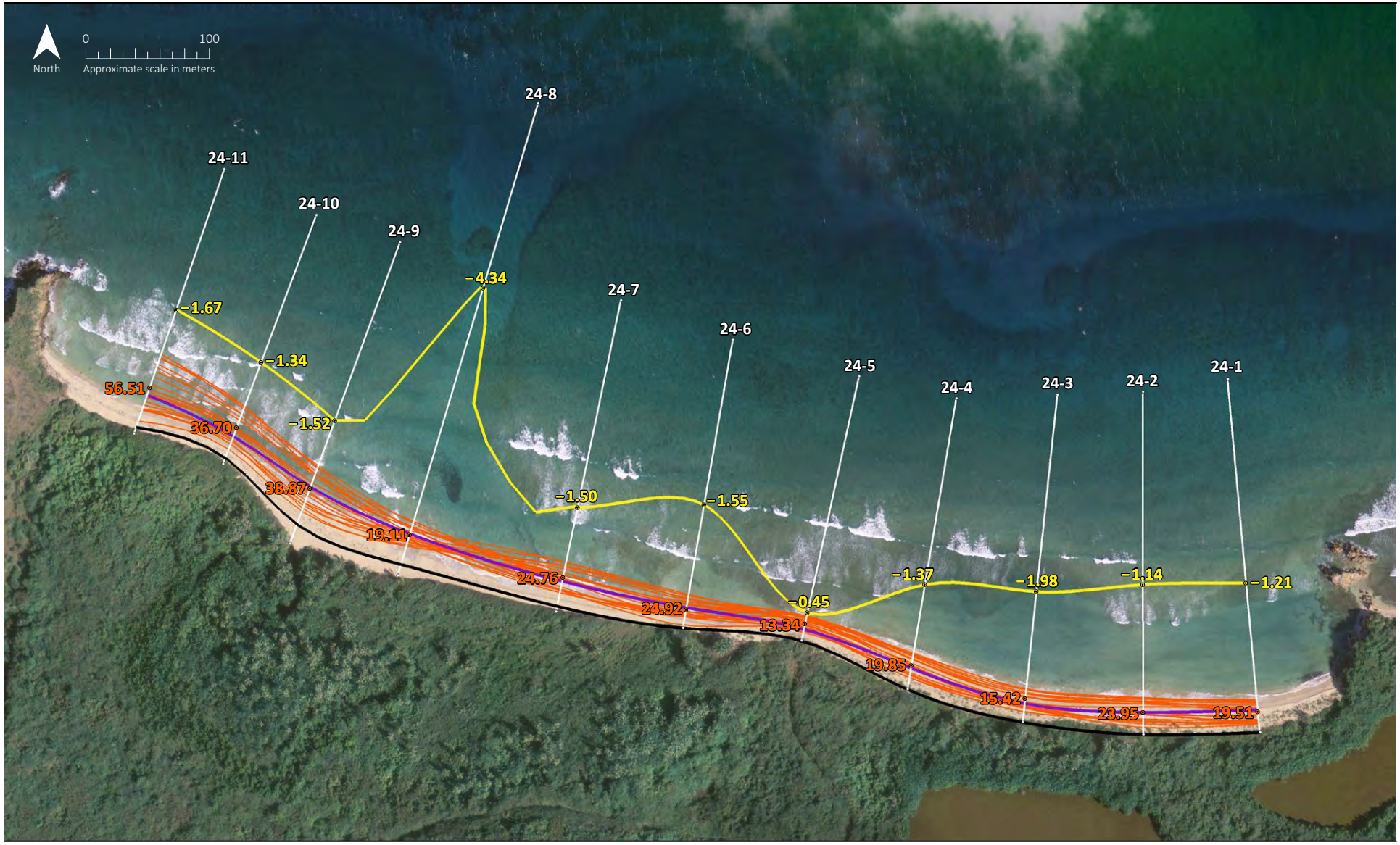
LEGEND

- Depth of closure
- Landward limit of beach change
- Shoreline positions and range of shoreline change
- Maximum beach elevation change

NOTE: All units are meters.

FIGURE 5-19
Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 22 (west)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.



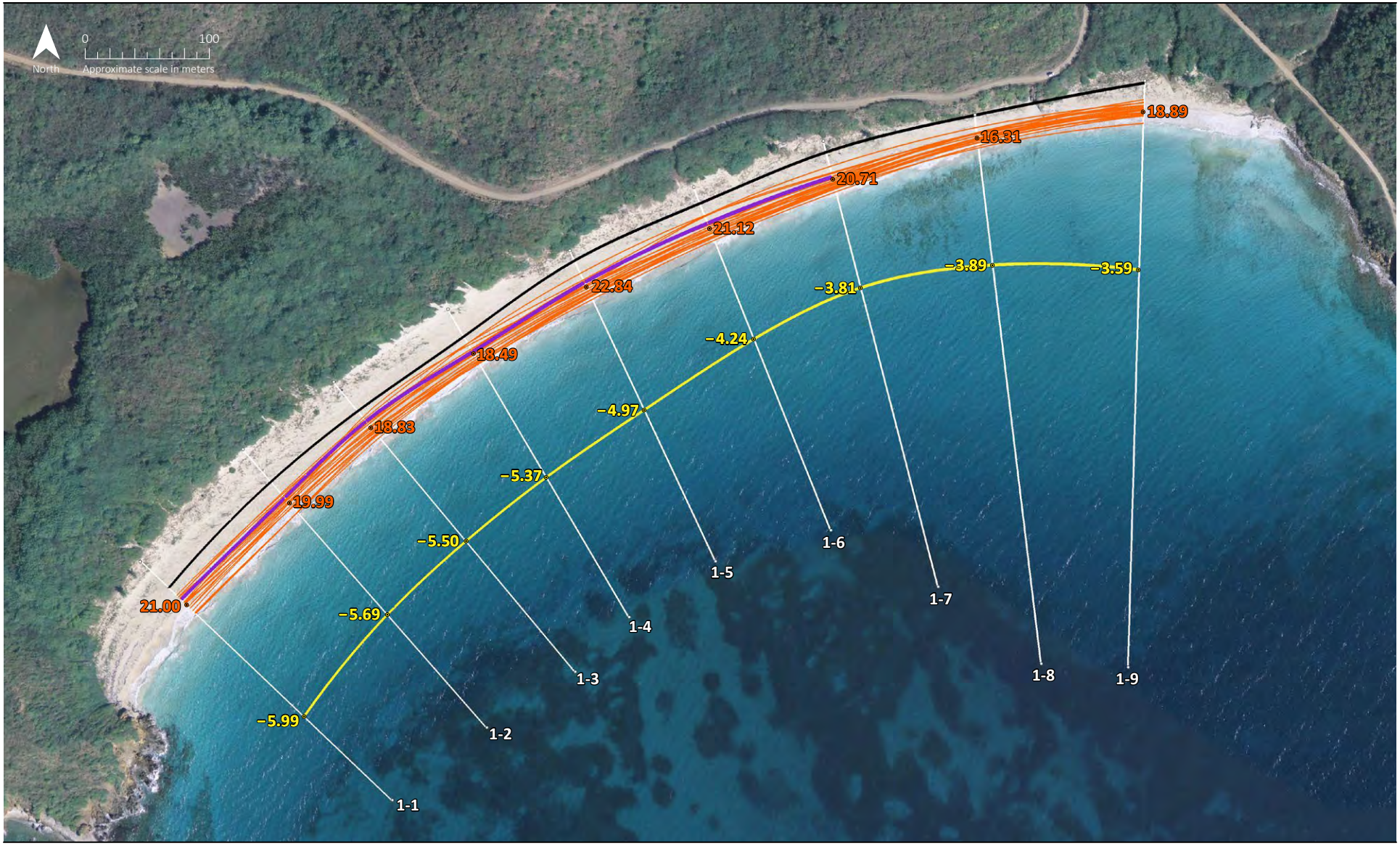
LEGEND

- Depth of closure
- Landward limit of beach change
- Shoreline positions and range of shoreline change
- Maximum beach elevation change

NOTE: All units are meters.

FIGURE 5-20
Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 24
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.



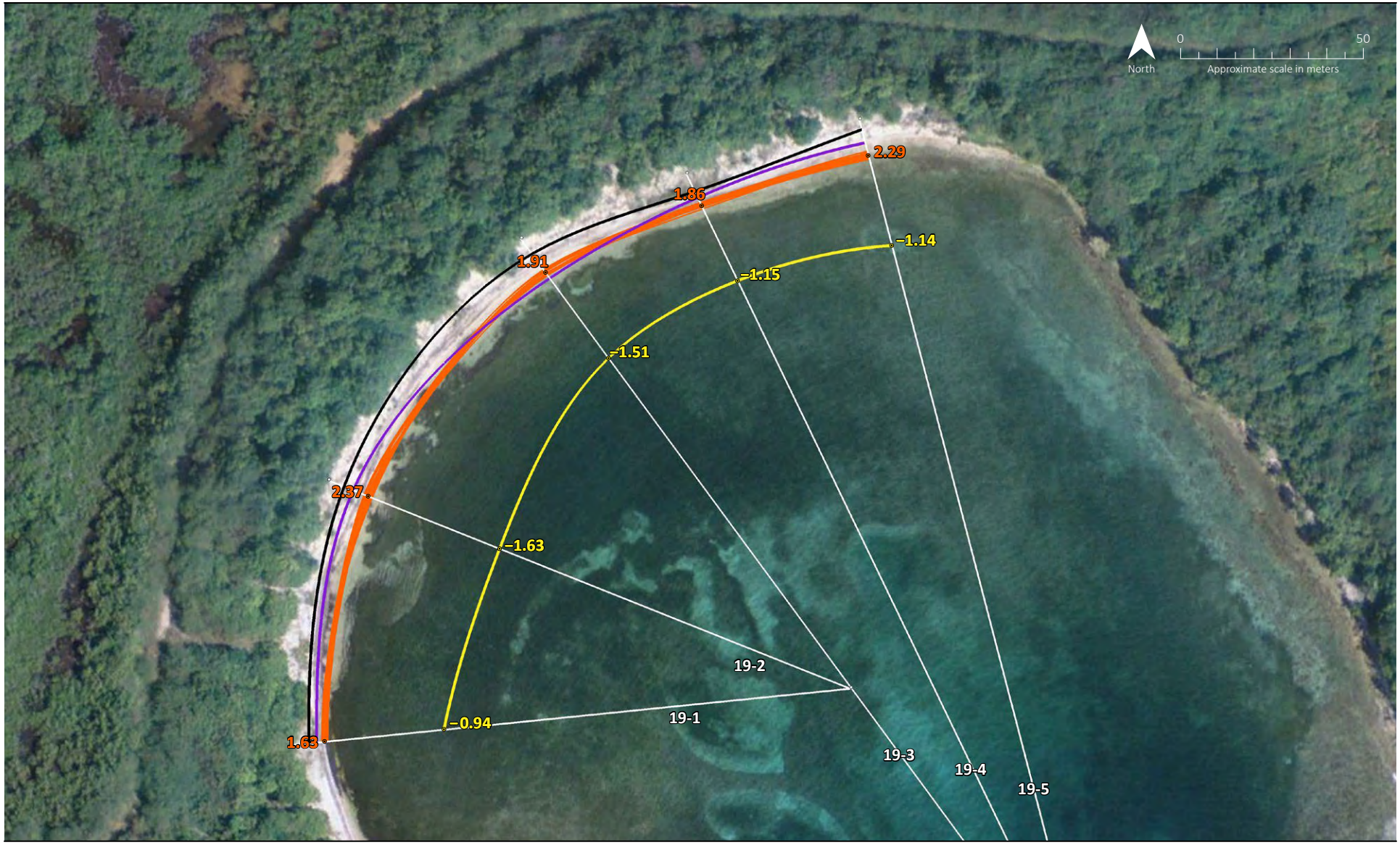
LEGEND

- Depth of closure
- Landward limit of beach change
- Shoreline positions and range of shoreline change
- Maximum beach elevation change

NOTE: All units are meters.

FIGURE 5-21
Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 1
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.



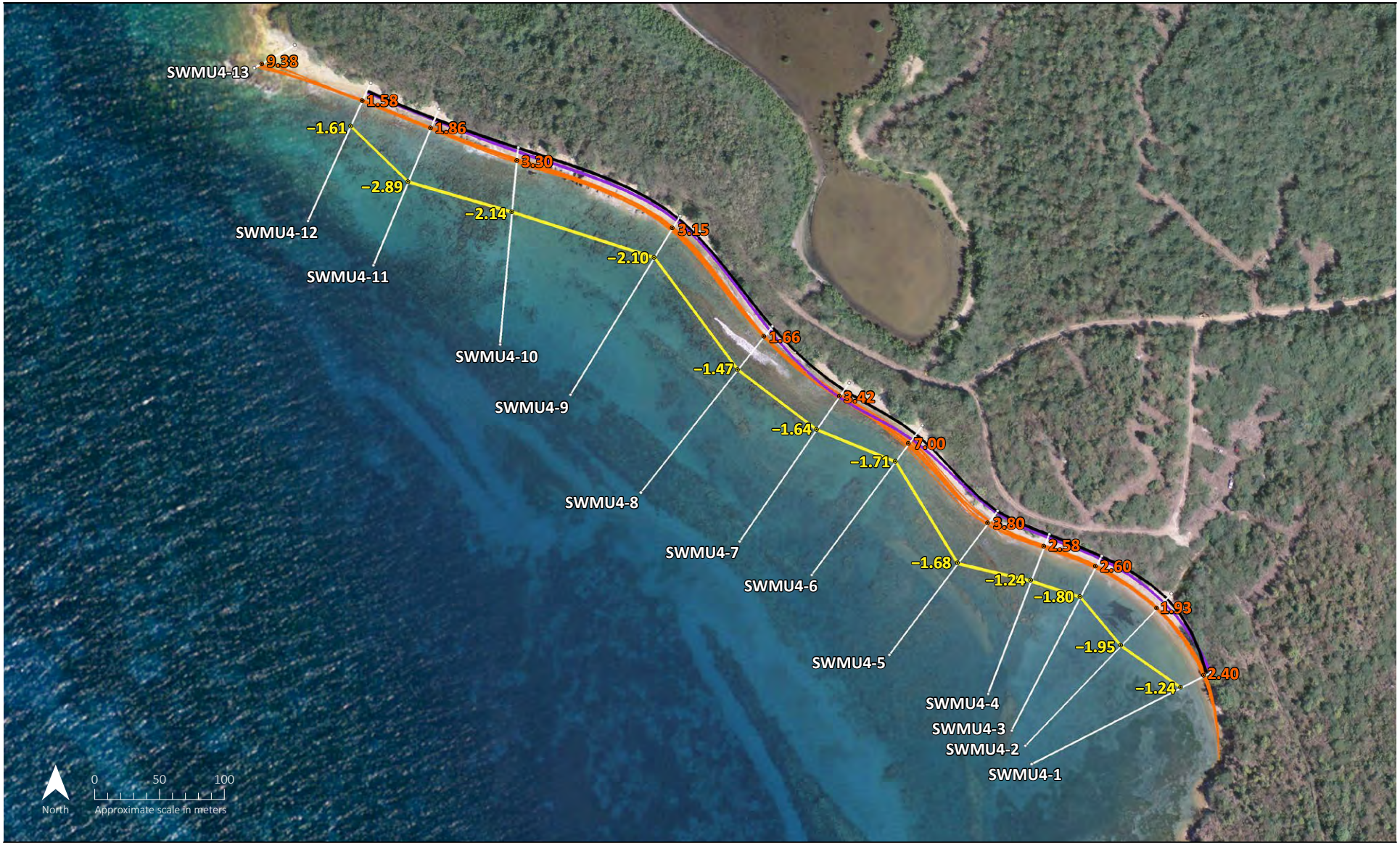
LEGEND

- Depth of closure
- Landward limit of beach change
- Shoreline positions and range of shoreline change
- Maximum beach elevation change

NOTE: All units are meters.

FIGURE 5-22
Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at Beach 19
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.



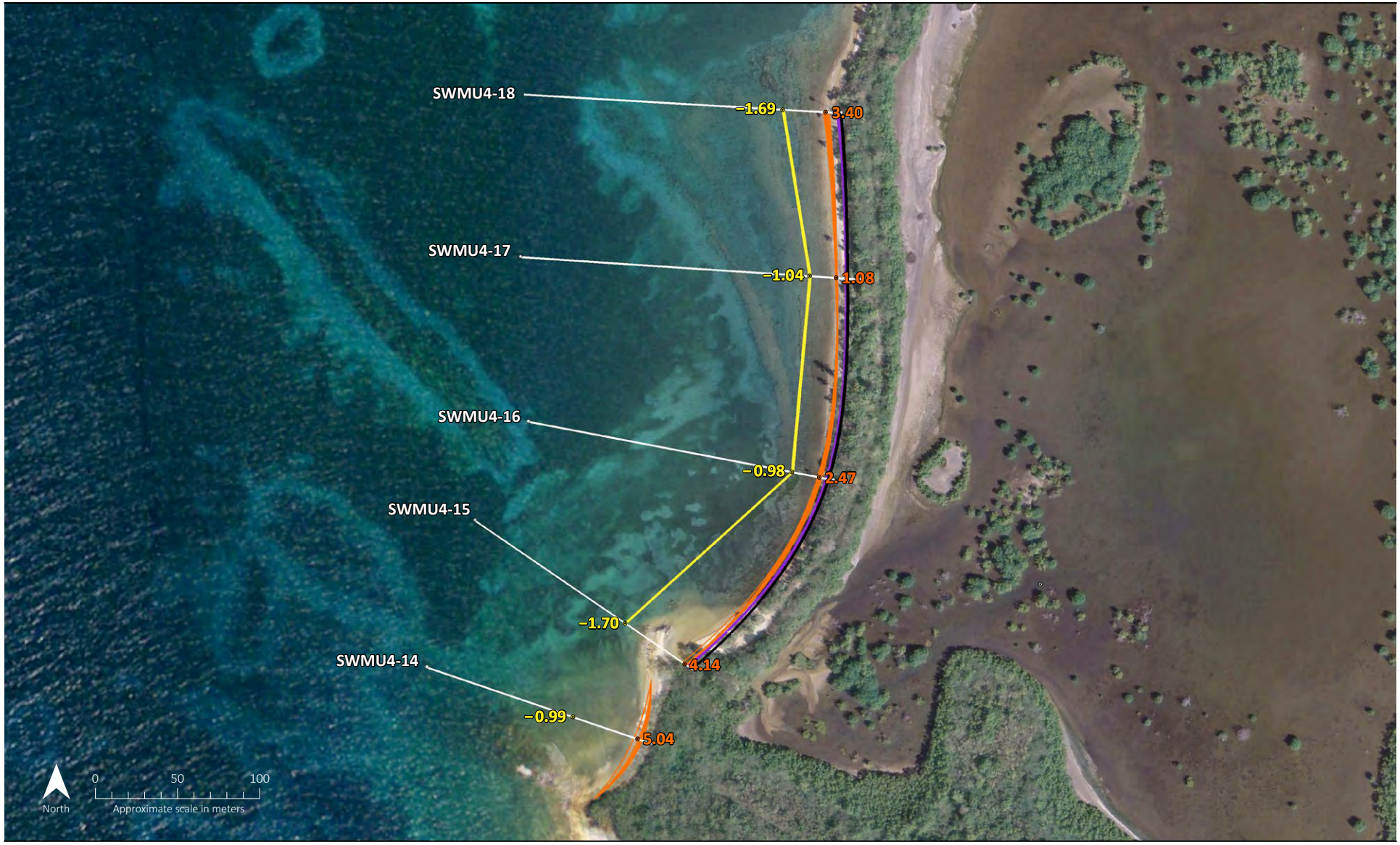
LEGEND

- Depth of closure (broken line = uncertain)
- Landward limit of beach change
- Shoreline positions and range of shoreline change
- Maximum beach elevation change

NOTE: All units are meters.

FIGURE 5-23
Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at SWMU 4 (southwest-facing)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image © 2018 DigitalGlobe. Image U.S. Geological Survey.



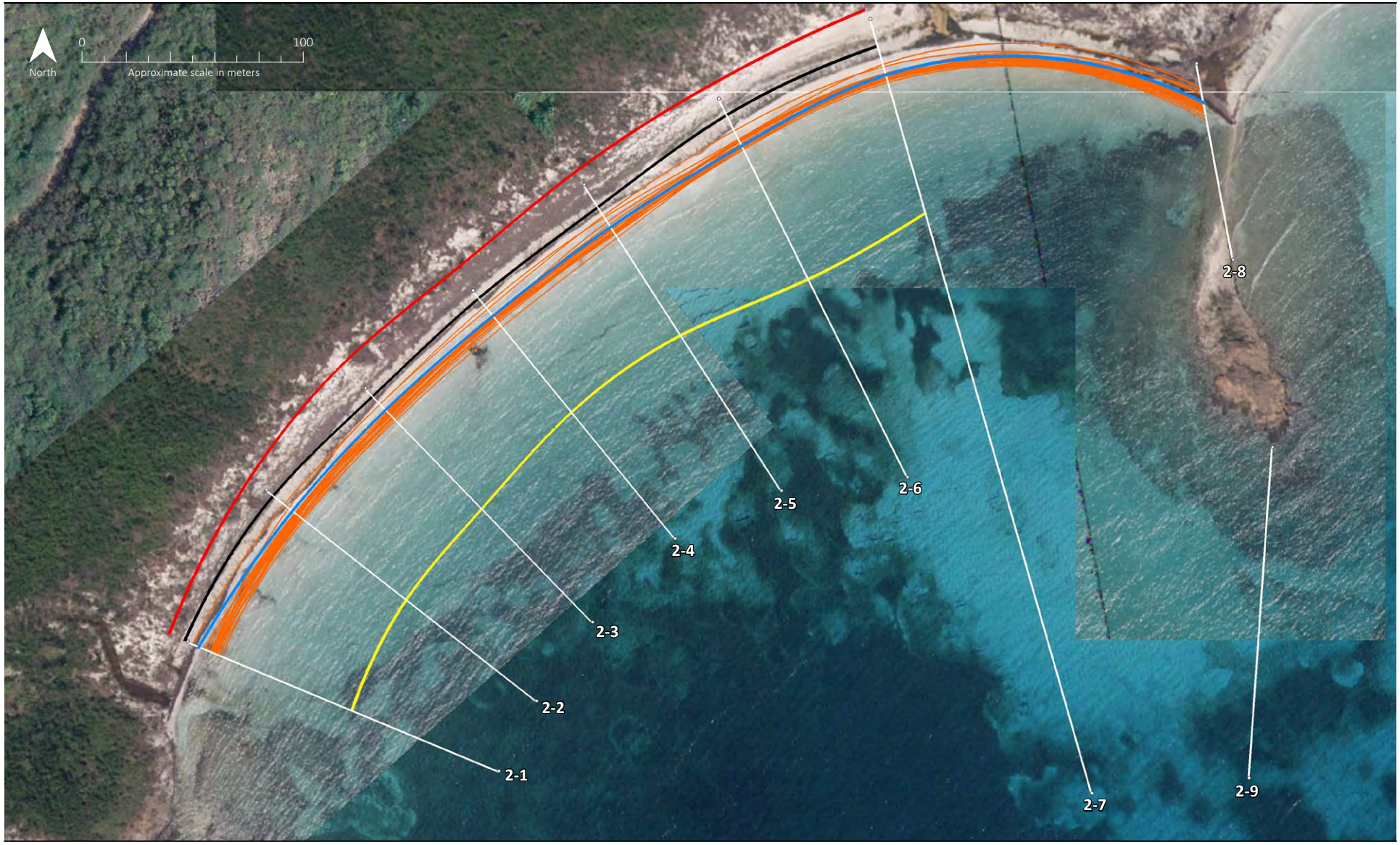
LEGEND

- Depth of closure (broken line = uncertain)
- Landward limit of beach change
- Shoreline positions and range of shoreline change
- Maximum beach elevation change

NOTE: All units are meters.

FIGURE 5-24
Depth of Closure (yellow), Landward Limit of Beach Change (black), Shoreline Positions (and range of shoreline change, orange) and Maximum Beach Elevation Change (purple) at SWMU 4 (west-facing)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.

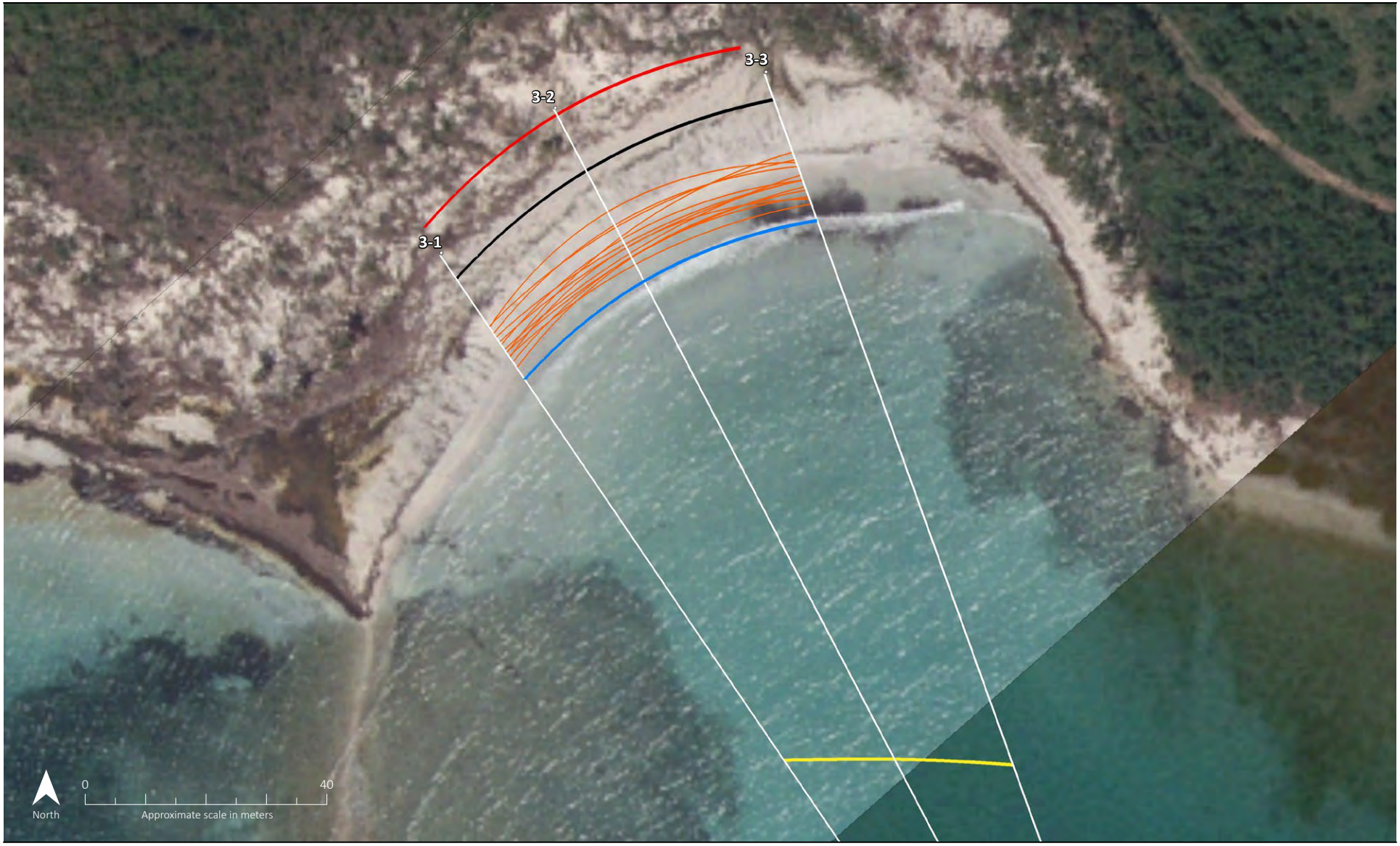


LEGEND

- Depth of closure
- Landward limit of beach change during the BDI
- Landward limit of beach change post-Maria
- Shoreline positions during the BDI
- Shoreline positions post-Maria

FIGURE 5-25
Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 2
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image © 2018 CNES/Airbus.

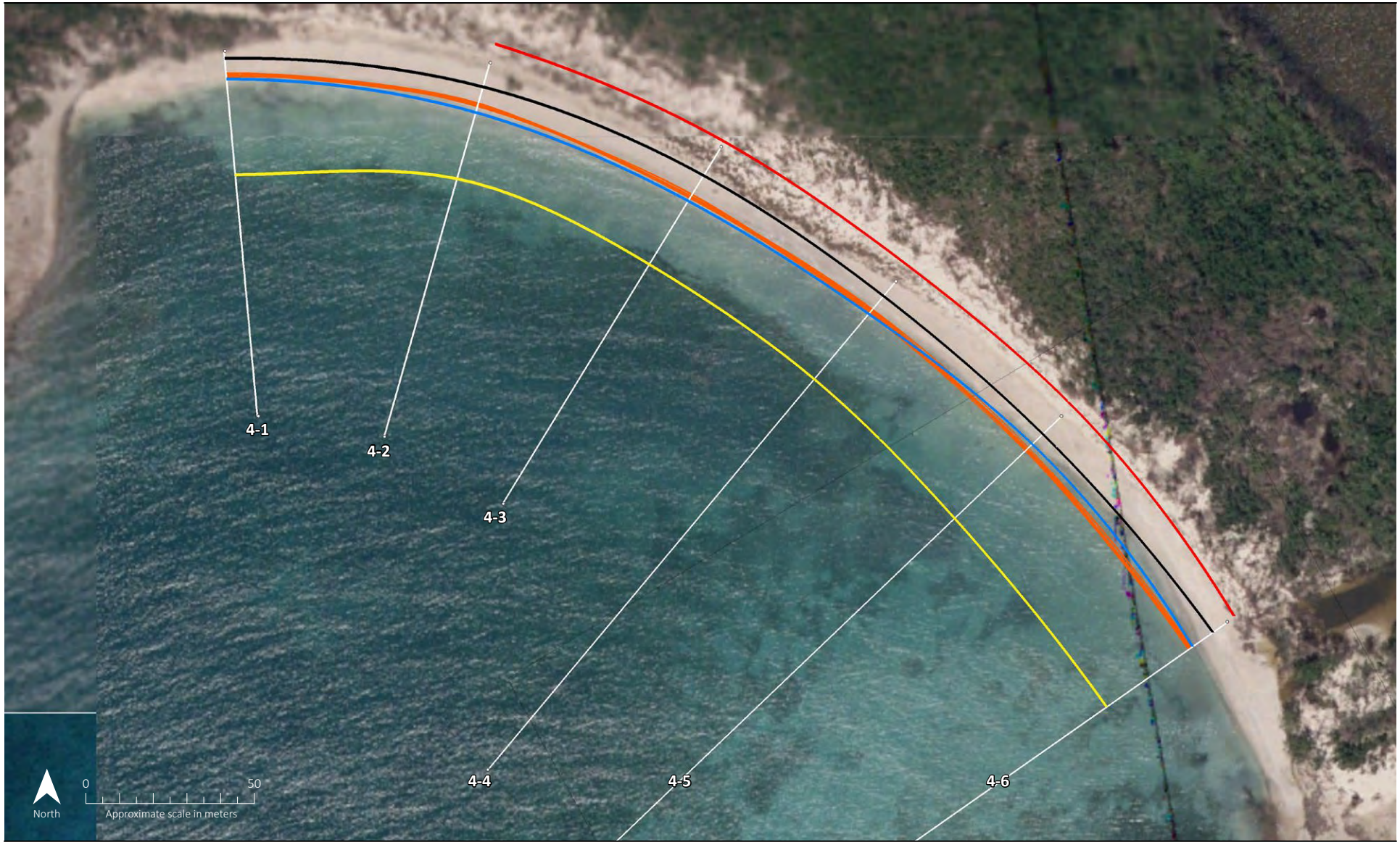


LEGEND

- Depth of closure
- Landward limit of beach change during the BDI
- Landward limit of beach change post-Maria
- Shoreline positions during the BDI
- Shoreline positions post-Maria

FIGURE 5-26
Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 3
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.

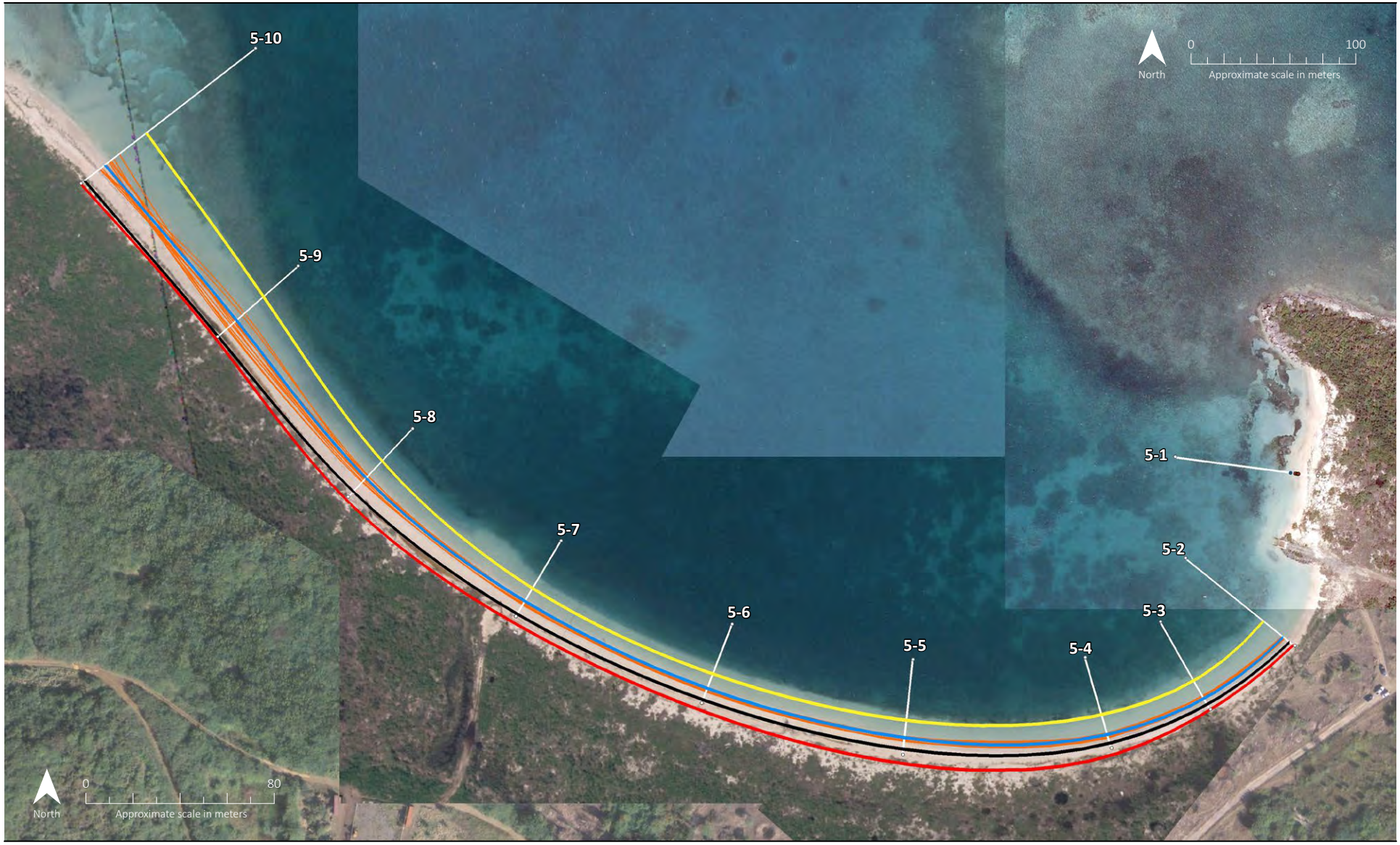


LEGEND

- Depth of closure
- Landward limit of beach change during the BDI
- Landward limit of beach change post-Maria
- Shoreline positions during the BDI
- Shoreline positions post-Maria

FIGURE 5-27
Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 4
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.

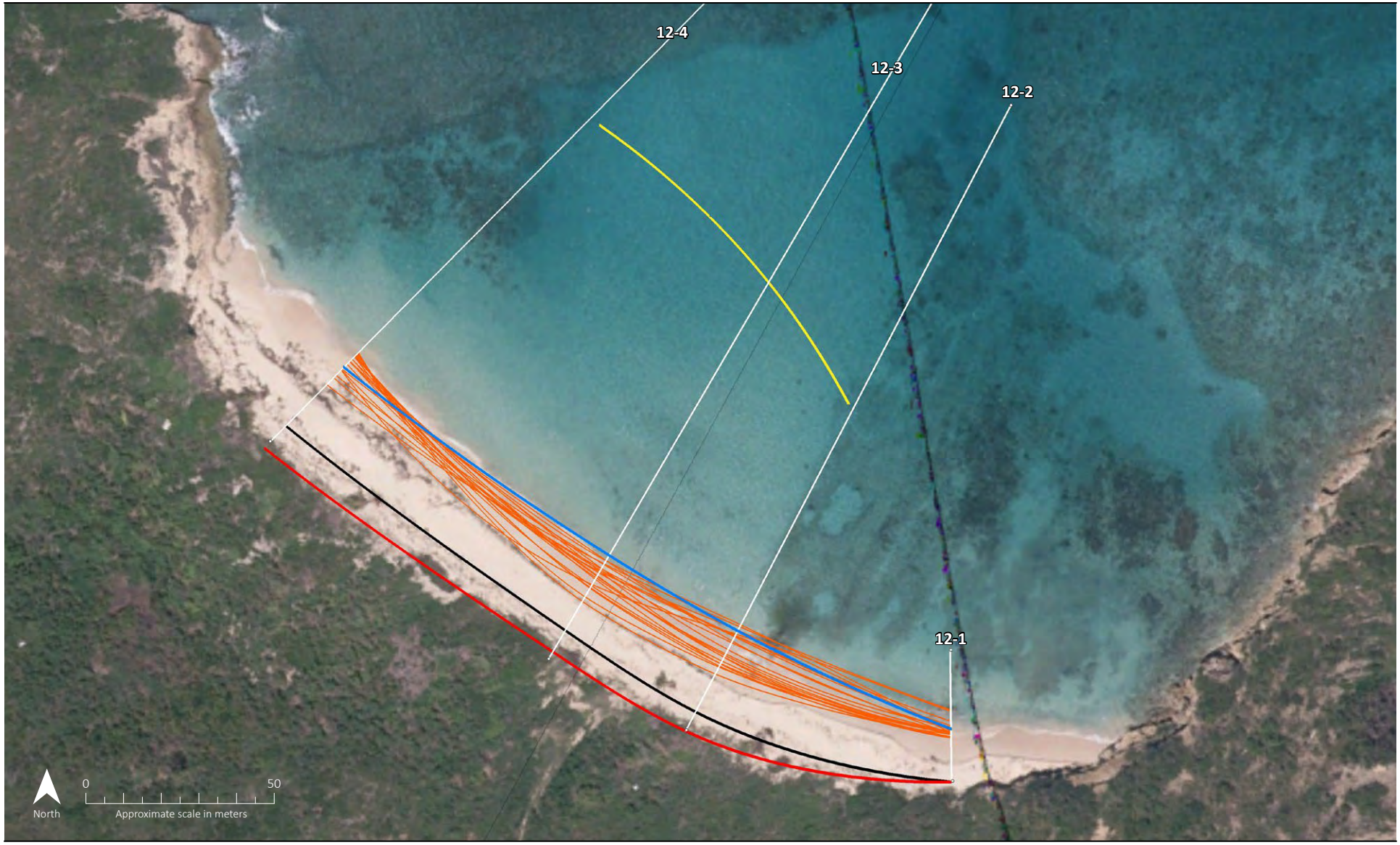


LEGEND

- Depth of closure
- Landward limit of beach change during the BDI
- Landward limit of beach change post-Maria
- Shoreline positions during the BDI
- Shoreline positions post-Maria

FIGURE 5-28
Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 5
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.

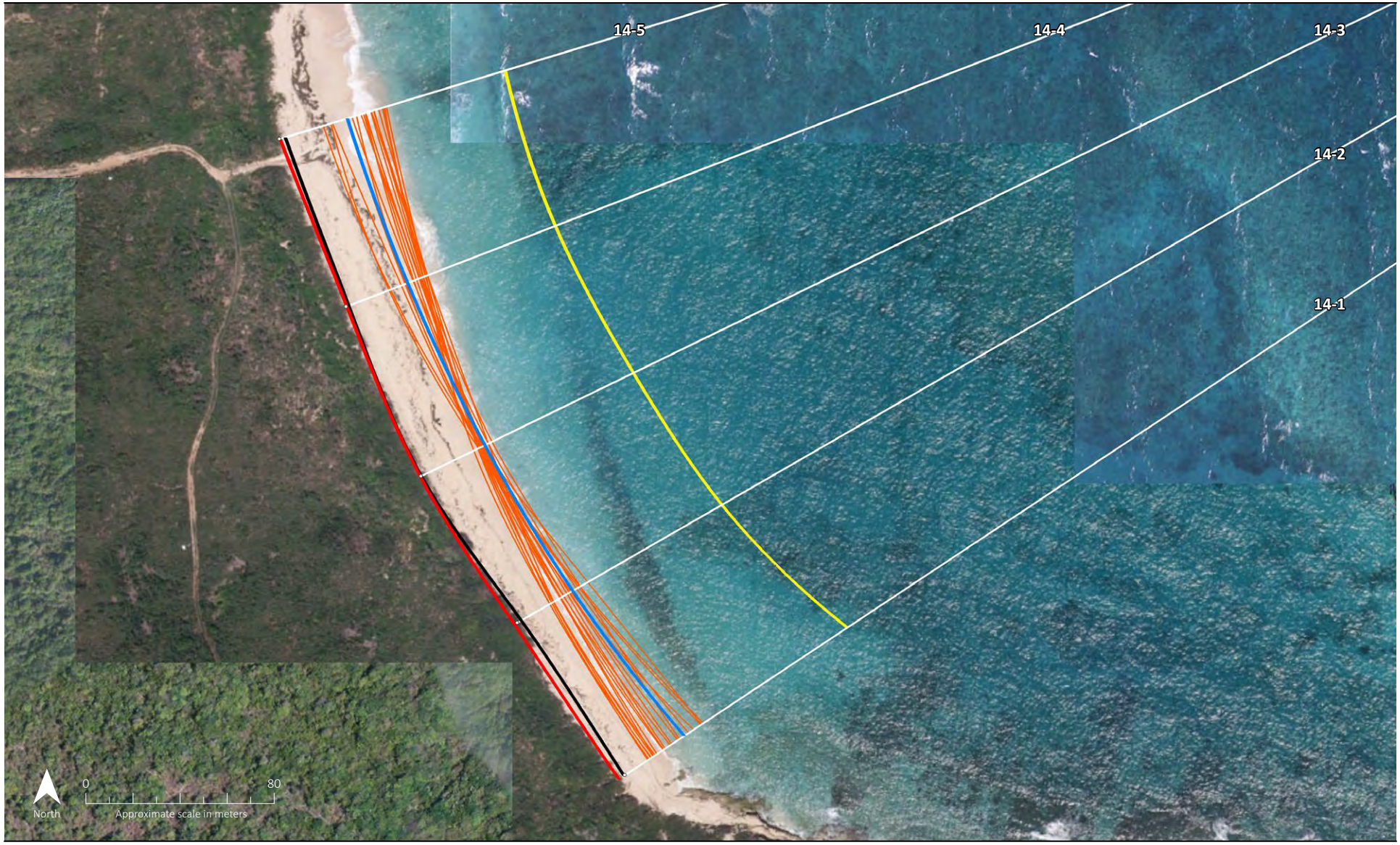


LEGEND

- Depth of closure
- Landward limit of beach change during the BDI
- Landward limit of beach change post-Maria
- Shoreline positions during the BDI
- Shoreline positions post-Maria

FIGURE 5-29
Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 12
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.

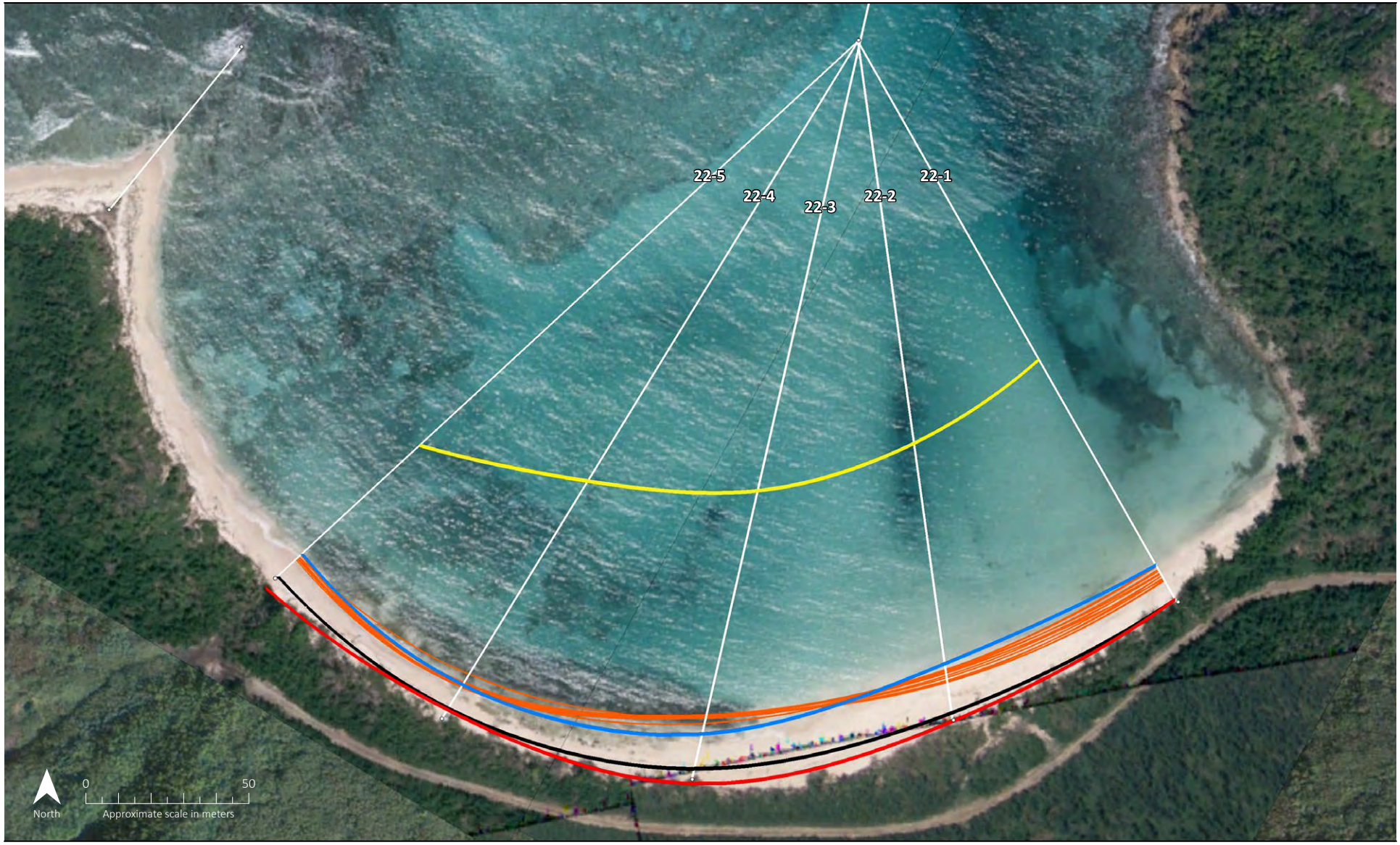


LEGEND

- Depth of closure
- Landward limit of beach change during the BDI
- Landward limit of beach change post-Maria
- Shoreline positions during the BDI
- Shoreline positions post-Maria

FIGURE 5-30
Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 14
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.

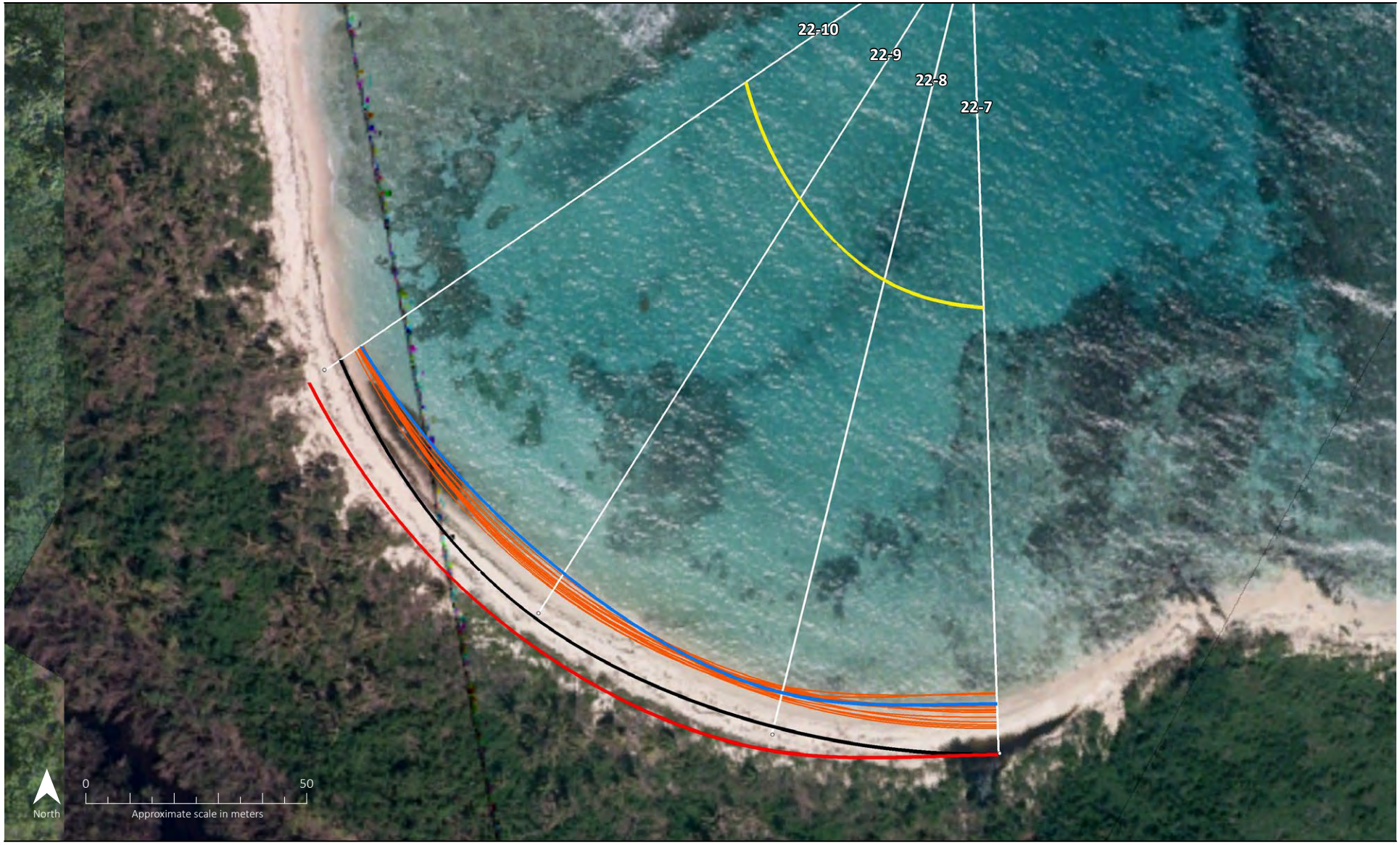


LEGEND

- Depth of closure
- Landward limit of beach change during the BDI
- Landward limit of beach change post-Maria
- Shoreline positions during the BDI
- Shoreline positions post-Maria

FIGURE 5-31
Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 22 (east)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.

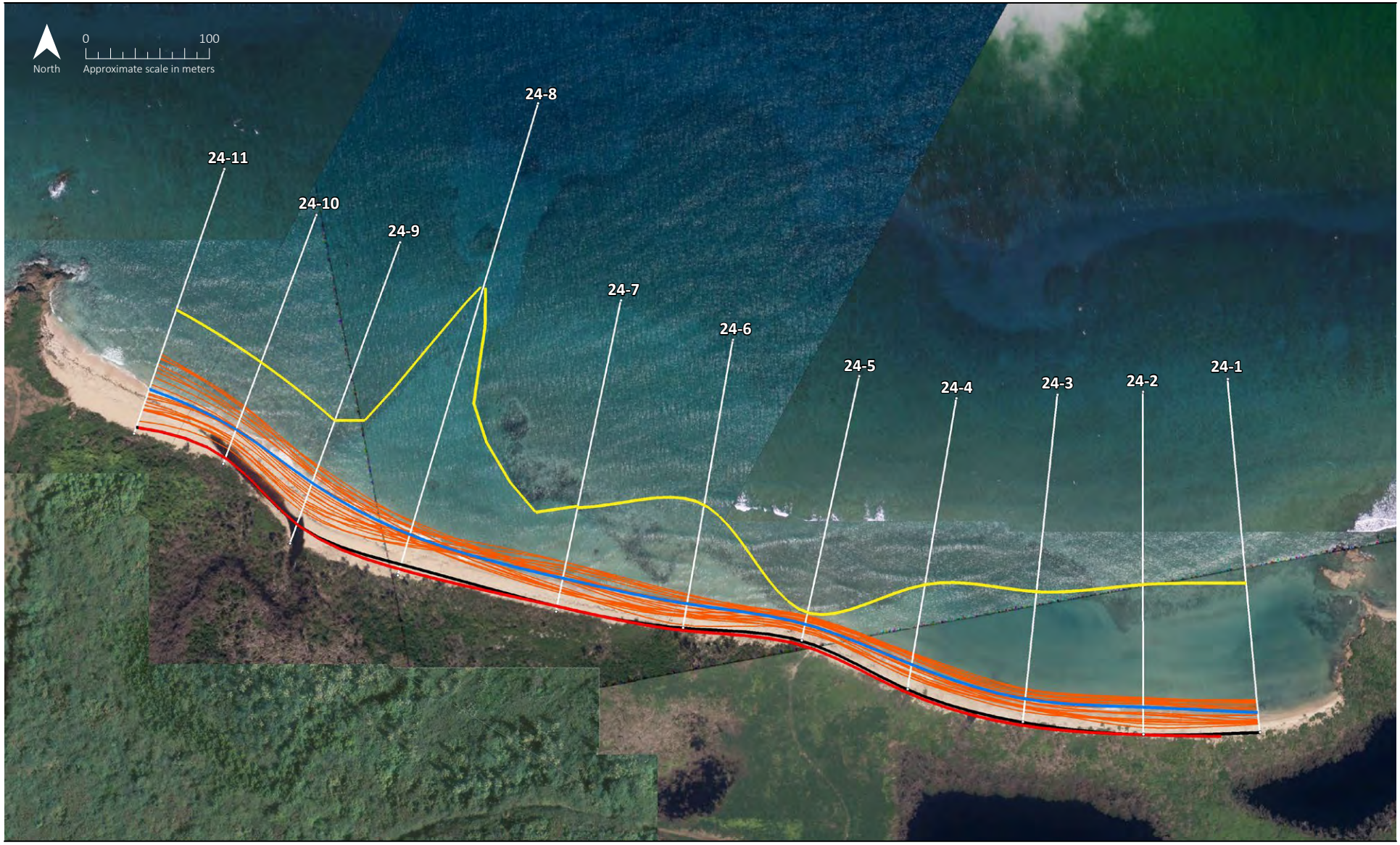


LEGEND

- Depth of closure
- Landward limit of beach change during the BDI
- Landward limit of beach change post-Maria
- Shoreline positions during the BDI
- Shoreline positions post-Maria

FIGURE 5-32
Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 22 (west)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.

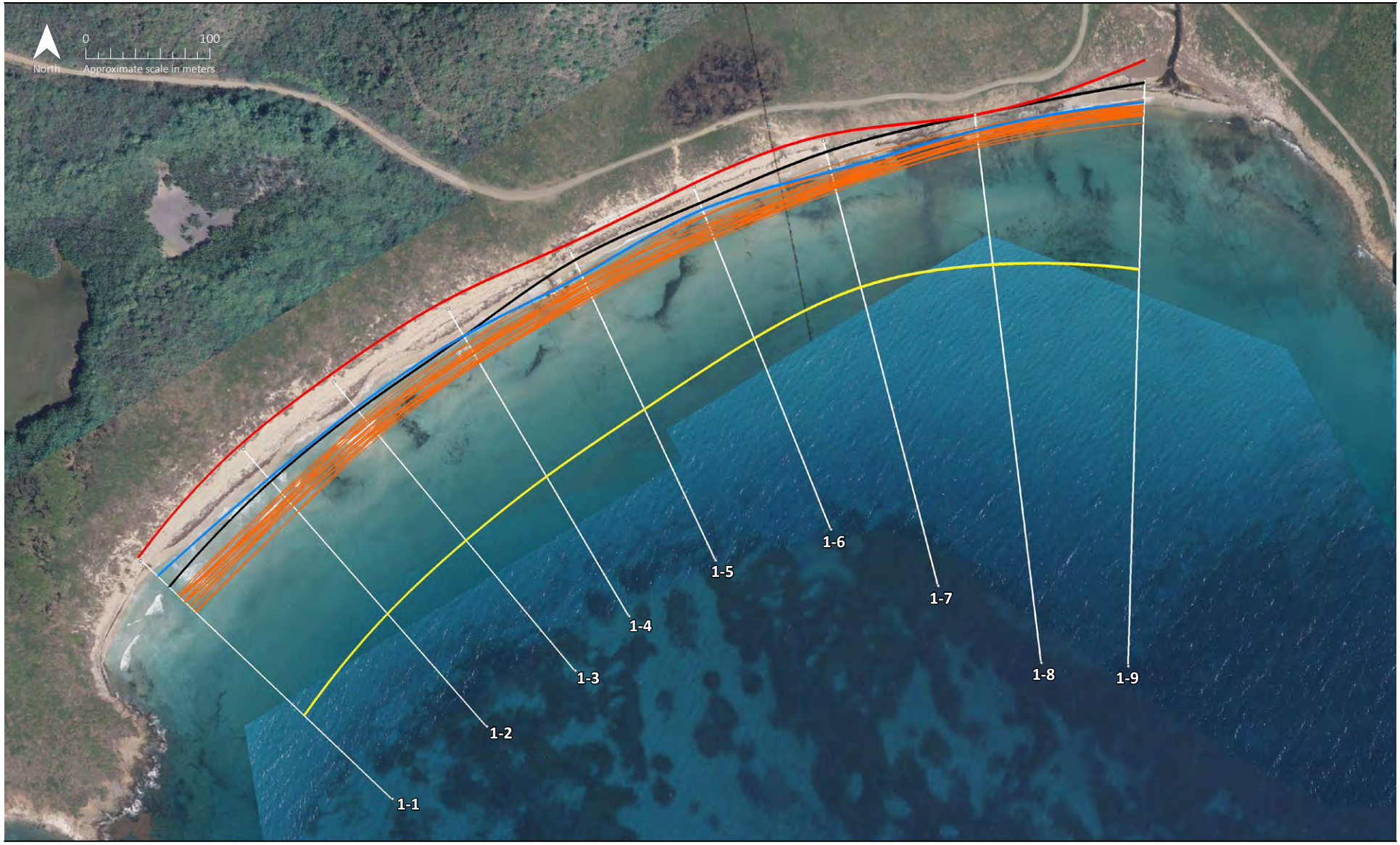


LEGEND

- Depth of closure
- Landward limit of beach change during the BDI
- Landward limit of beach change post-Maria
- Shoreline positions during the BDI
- Shoreline positions post-Maria

FIGURE 5-33
Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 24
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.

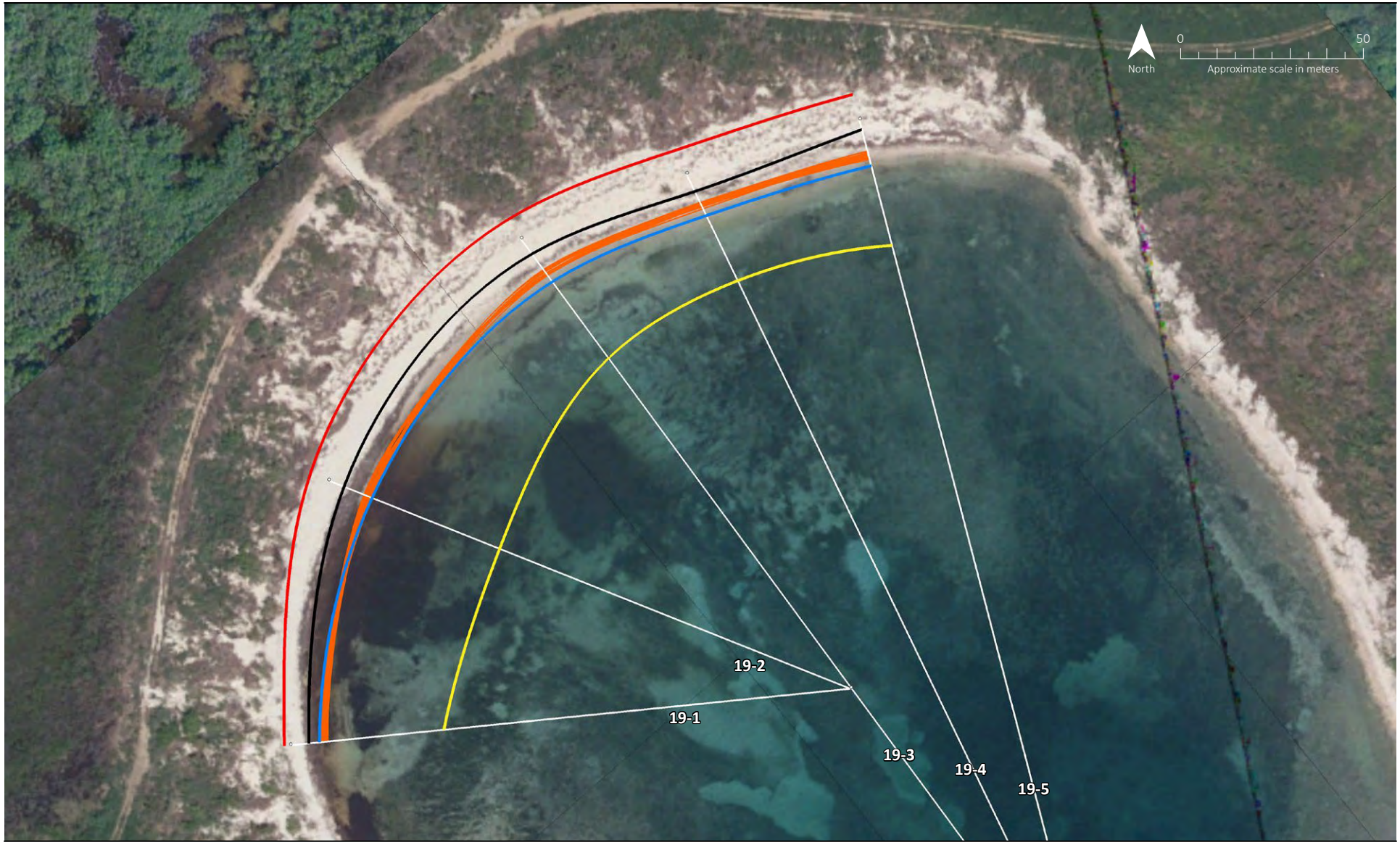


LEGEND

- Depth of closure
- Landward limit of beach change during the BDI
- Landward limit of beach change post-Maria
- Shoreline positions during the BDI
- Shoreline positions post-Maria

FIGURE 5-34
Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 1
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.

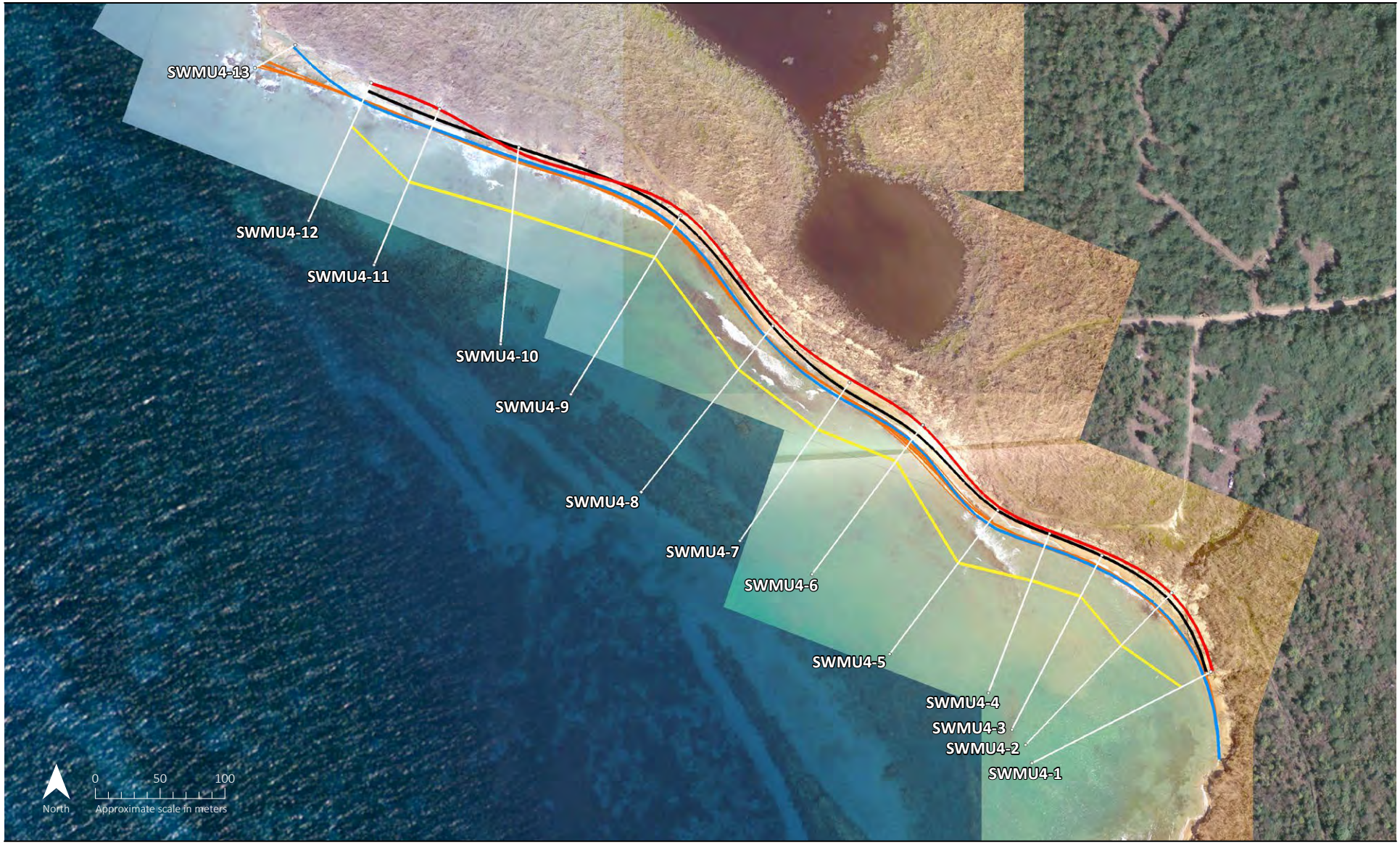


LEGEND

- Depth of closure
- Landward limit of beach change during the BDI
- Landward limit of beach change post-Maria
- Shoreline positions during the BDI
- Shoreline positions post-Maria

FIGURE 5-35
Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at Beach 19
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image U.S. Geological Survey.

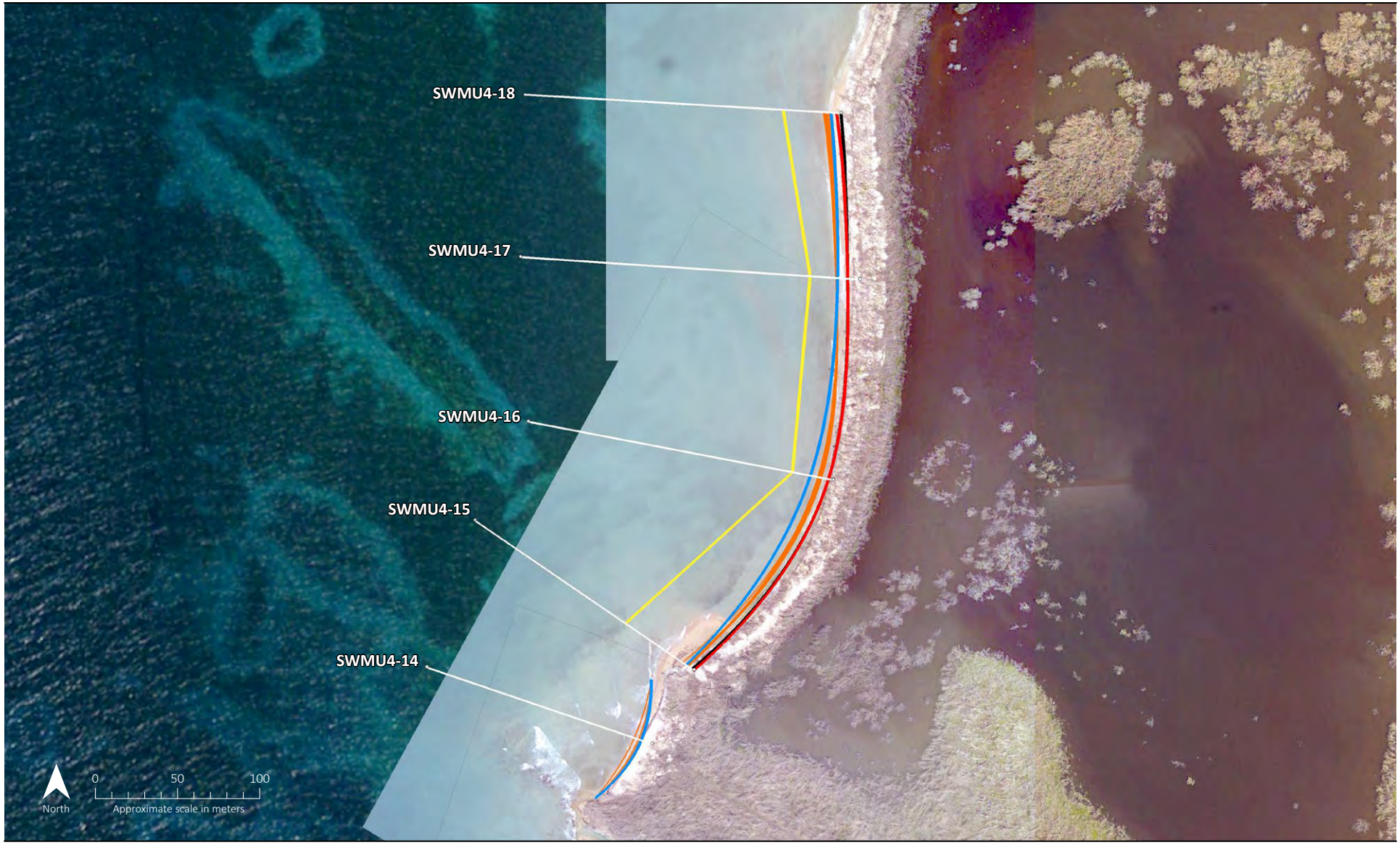


LEGEND

- Depth of closure
- Landward limit of beach change during the BDI
- Landward limit of beach change post-Maria
- Shoreline positions during the BDI
- Shoreline positions post-Maria

FIGURE 5-36
Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at SWMU 4 (southwest-facing)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2018 Google Earth. Image © 2018 DigitalGlobe. Image U.S. Geological Survey.



LEGEND

- Depth of closure
- Landward limit of beach change during the BDI
- Landward limit of beach change post-Maria
- Shoreline positions during the BDI
- Shoreline positions post-Maria

FIGURE 5-37
Depth of Closure (yellow), Landward Limit of Beach Change During the BDI (black) and Post-Maria (red), and Shoreline Positions During the BDI (orange) and Post-Maria (blue) at SWMU 4 (west-facing)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

FIGURE 5-38
Strafing Target at the East End of Beach 2 (Transect 7), Post-Maria
Beach Dynamics Investigation Report
Vieques, Puerto Rico

FIGURE 5-39
Ephemeral Stream at the West End of Beach 2 (Transect 1), Post-Maria
Beach Dynamics Investigation Report
Vieques, Puerto Rico

FIGURE 5-40
Laguna Anones Inlet at Beach 4
(Transect 6), Post-Maria
Beach Dynamics Investigation Report
Vieques, Puerto Rico

FIGURE 5-41
Laguna Puerto Diablo Overflow at Beach 22
(Transect 5), Post-Maria
Beach Dynamics Investigation Report
Vieques, Puerto Rico

FIGURE 5-42
Surface Water Runoff at Beach 22
(Transect 7), Post-Maria
Beach Dynamics Investigation Report
Vieques, Puerto Rico

FIGURE 5-43
Previously Buried Concrete Blocks at Beach 1, Exposed Post-Maria
Beach Dynamics Investigation Report
Vieques, Puerto Rico

FIGURE 5-44
Ephemeral Stream at SWMU 4
(Transect 1), Post-Maria
Beach Dynamics Investigation Report
Vieques, Puerto Rico

FIGURE 5-45
Laguna Boca Quebrada Inlet at SWMU 4
(Transect 15), Post-Maria
Beach Dynamics Investigation Report
Vieques, Puerto Rico

SECTION 6

Summary and Conclusions

The BDI was performed to augment the current understanding of the dynamic behavior of the beaches and metocean conditions in Vieques and their impact on the burial and mobility of MEC. This understanding will assist future decision-making processes with regards to investigations, removal/remedial action determinations, and long-term monitoring/operations and maintenance, as applicable.

Based on the information provided in Sections 1 through 5, the objectives of the BDI were met via the approach summarized below.

6.1 BDI Summary

- The BDI focused on 10 beaches at the former VNTR and 1 beach at the former NASD. Beaches selected are representative of the remainder of the beaches in the former VNTR and NASD, as they include the broad range of characteristics found across Vieques.
- The BDI approach included the following:
  - Continuous wave measurements from three AWACs installed located offshore on the north, east, and south coasts of Vieques to characterize wave conditions and assess their impacts on beach changes and burial and mobility of MEC
  - Collection of concurrent water level measurements from NOAA Stations to assess the impact of water levels on beach changes
  - Continuous rainfall measurements to assess impacts on surface water runoff, beach changes, and burial and mobility of MEC
  - Monthly beach surveys to measure and evaluate beach changes
  - Quarterly sediment grain size sampling and analysis to determine beach sediment size and cross-shore distribution and for use as part of input in potential MEC burial and mobility prediction models
  - Monthly MEC surrogate surveys to evaluate burial and mobility of underwater MEC in the nearshore environment under the effect of beach changes, waves, currents, and water levels
  - Metocean field observations to help understand these conditions relative to measured beach changes
  - Third-party metocean data collection to characterize corresponding local and regional conditions during the BDI
- The BDI activities were conducted from October 2014 through February 2016; however, additional survey/measurements were conducted in October and November 2017 to evaluate impacts from Hurricanes Irma and Maria.

6.2 BDI Conclusions

Beach changes and MEC burial and mobility are mainly driven by waves, wind-, wave- and tide-induced currents, and water levels. Therefore, knowledge of these conditions is critical for the understanding and prediction of these processes. It was concluded that during the BDI (the timeframe of which did not include the two hurricanes), wind and wave climates, water level changes and resulting induced currents were typical and, consequently, resulting beach changes, and burial and mobility of the MEC surrogates were also typical.

A summary of the beach dynamics results is included in **Table 6-1**. These results were analyzed with the objective of determining the common features, conditions at, and responses of the BDI beaches that could be used not only to inform future activities (as previously described), but also as proxies to estimate similar responses in non-BDI beaches of interest around Vieques.

6.2.1 Dynamics

- The BDI helped identify dynamic and stable beaches. Dynamic beaches, such as Beaches 1, 2, 12, 14 and 24, are exposed (oriented) toward the typical wave climate and/or have no or little protection from headlands, bays, and reefs. Stable beaches, such as 3, 4, 19, 5, 22 and SWMU 4, are not exposed to the typical wave climate and/or are protected by headlands, bays, and reefs.

6.2.2 Beach Profiles

- At dynamic beaches, beach profiles landward or seaward of the shoreline exhibited average maximum elevation changes greater than 0.8 m, while at stable beaches these changes were less than 0.8 m. An exception was Beach 22 (west) where waves, bathymetry and a headland interacted at transect 7 to generate a profile elevation change of 1.48 m. This exceeded what was typical elsewhere at this beach and biased the average maximum elevation change to 0.96 m.

6.2.3 Areas of Beach Change

- Of importance for the BDI was the definition of the areas of potential beach change as the burial and mobility of MEC in these areas could be significantly affected by the processes that drive the beach changes. These areas are bounded by the depth of closure in the nearshore and the landward limit of beach change in the backshore. Beyond these limits, no significant changes are expected to occur in typical conditions.
- The BDI showed that the width of the area of beach change was greater than 50 m at dynamic beaches, and less than 50 m at stable beaches. Exceptions were Beaches 3 and 22. At these beaches, the flat and broad nearshore bottoms, and relatively small bottom elevation variations combined with the potential differences introduced by the inherent resolution and repeatability limitations of the surveys to introduce uncertainty in the estimation of the depth of closure, and in the width of the area of beach change. Regardless, other characteristics as described in this section, classify these beaches as stable.

6.2.4 Depth of Closure

- The BDI showed that, at dynamic beaches, depths of closure are greater than -2 m PRVD02, while at stable beaches these are less than -2 m PRVD02. Exceptions were Beaches 22 and SWMU 4 where flat and broad nearshore bottom, presence of reefs, and relatively small bottom elevation variations combined with the potential differences introduced by the inherent resolution and repeatability limitations of the surveys to introduce uncertainty in the estimation of the depth of closure. Regardless, other characteristics as described in this section, classify these beaches as stable.

6.2.5 Landward Limit of Beach Change

- At all beaches, the landward limit of beach change was generally parallel to the shoreline and, at some locations, it bordered the vegetation line.
- The BDI showed that wave heights in the nearshore at dynamic beaches were greater than 0.5 m, while at stable beaches wave heights were less than 0.5 m to negligible. This translated into corresponding higher and lower wave runup that reached higher and lower elevations on the beach slopes, respectively. At the dynamic beaches where the waves were higher, the landward limit of beach change reached average elevations greater than 1 m PRVD02, while at stable beaches the average elevation changes were less than 1 m PRVD02.
- Although not an objective of the BDI, from an ecological perspective, the landward limit of beach change information can be used to help understand the effects of beach dynamics on sea turtle nesting habitats.

6.2.6 Shoreline Position

- The BDI showed that, at dynamic beaches, the ranges of shoreline positions were greater than 5 m, while at stable beaches these were less than 5 m. Exceptions were Beaches 3, 5 and 22. At Beach 3 large mounds of Sargassum were occasionally formed protecting the beach landward of the shoreline and reflecting incoming

waves seaward. The reflected waves combined with the incident waves to augment sediment transport, in particular, at the seaward edge of the mounds (i.e., at the shoreline). At Beach 5, the range of shoreline change in most of the beach was less than 5 m, except at the western end where the shoreline is shaped by the sediment transport forced by easterly wind-generated waves within the bay, and the offshore waves that refract around Yallis Island and move sediment back into the bay. At Beach 22, the headland splitting this beach into 2 beaches (the Beach 22 East and Beach 22 West) produced an approximately 8 m range of shoreline change on its west side, which exceeded changes elsewhere at this beach.

South Coast

- At the dynamic beaches on the south coast of the VNTR (Beaches 1 and 2), shoreline positions varied uniformly along the beach, which suggests a relatively high wave environment and a dominant cross-shore sediment transport direction. At the stable beaches on the south coast, Beaches 4 and 19, shoreline positions showed negligible variations, which indicates a low wave environment and negligible sediment transport. An exception to this was Beach 3, where the occasional presence of Sargassum mounds on the beach along the shoreline influenced the response of the beach.

East Coast

- On the east coast of the VNTR, Beaches 12 and 14 are dynamic and shoreline positions varied, alternatively accreting and eroding at the ends in a cyclical fashion in response to the seasonal changes in wave direction, suggesting a relatively high wave environment and a dominant longshore transport of sediment.

North Coast

- On the north coast of the VNTR, Beaches 5 and 22 are stable beaches, where shoreline position changes are small along the majority of the beach which indicates a low wave environment and negligible sediment transport. Beach 24 on the north coast is dynamic and shoreline positions varied alternatively accreting and eroding at the ends in a cyclical fashion in response to the seasonal changes in wave direction, suggesting a relatively high wave environment and a dominant longshore transport of sediment.

West Coast

- On the west coast, SWMU 4 is a stable beach, where sediment transport is negligible due to the low wave environment that results from the wave protection offered by the shallow reefs and the orientation of the beach relative to the predominant easterly waves.

6.2.7 Hurricane Maria Shoreline Position Impacts

- Hurricane Maria on September 20, 2017, was one of the most devastating hurricanes that hit Vieques in recent times. The post-Maria beach reconnaissance and beach surveys, and the wave hindcast and hydrodynamic modeling allowed facilitated assessing the condition of the BDI beaches and estimate the wave conditions and storm surge that impacted the beaches. Maria generated high waves and storm surge which were particularly damaging on Vieques' south coast.

South Coast

- On the south coast of the VNTR, Hurricane Maria's 1 to 3 m, 14-second waves from the southeast impacted Beaches 1 and 2 (in order of significance) and moved large amounts of sediment, likely and predominantly from the beach to the nearshore up to and beyond the depth of closure, but possibly also from offshore into this area.
- At Beaches 3, 4 and 19, sediment was moved to the nearshore, possibly from offshore, given that at those beaches there were no significant changes landward of the shoreline. The inspection of aerial photos showed changes beyond the landward limits of beach erosion derived from the beach surveys, but these were attributed to the transport of sand and erosion of vegetation by wind.

East Coast

- On the east coast of the VNTR, Hurricane Maria's 2 m, 13-second waves from the east impacted Beaches 12 and 14 but no significant erosion or accretion of sediment was noted. The inspection of aerial photos did not show changes beyond the landward limits of beach change derived from the beach surveys.

North Coast

- On the north coast of the VNTR, Hurricane Maria's 1 to 1.5 m, 10-second waves from the northeast impacted Beaches 5, 22, 24. While not as significant as on the beaches on the south coast, Beaches 5 and 22 showed accretion of sediment in the nearshore, transported possibly from offshore given that the beach landward of the shoreline did not experience significant changes. At Beach 24, no significant erosion or accretion of sediment was noted, and backshore profiles were within the range of change during the BDI. The inspection of aerial photos did not show changes beyond the landward limits of beach erosion derived from the beach surveys.

West Coast

- On the west coast, the impact at southwest- and west-facing sections of the beach at SWMU 4 due to Hurricane Maria's 2 m, 13-second waves from the southwest was not significant, except at Punta Boca Quebrada which was completely eroded down to the rock substrate. No significant erosion or accretion of sediment was noted, except for accretion approximately 70 m beyond the shoreline and, particularly, near where the primary ephemeral stream occasionally flows to the sea during high rainfall events. At the west-facing section of the beach, the culvert connecting Laguna Boca Quebrada to the sea and the road bridge over the culvert were blocked/covered completely by a significant accretion of sediment. The inspection of aerial photos showed changes beyond the landward limits of beach erosion derived from the beach surveys, but these were attributed to the transport of sand and erosion of vegetation by wind.

6.2.8 Rainfall and Surface Water Runoff

- Rainfall, was lower than typical in 2015 and typical thereafter. During the BDI, survey crews did not observe lagoon inlets or ephemeral streams flowing to the bays redistributing sediment and altering beaches, except at Beaches 1, 22 and 24 following the extreme rainfall in November 2016. In these three cases, the beach berm breaches produced only localized changes on the beach.
- During the passage of Hurricanes Irma and Maria in September of 2017 heavy rainfall was observed, but no measurements were available. IMERG (2017) estimated that rainfall in Vieques during Hurricane Maria was in the order of 200 to 300 mm. Post-Maria beach reconnaissance performed the week of October 23, 2017, identified beach berm breaches due to lagoon and ephemeral stream high water levels at Beach 1, 2, 4, 22, 24, and SWMU 4. Relative to the 100-year (660 mm) and the extreme November 2016 (400 mm) rainfalls, the rainfall during Hurricane Maria (200 to 300 mm) was not extreme, but combined with the rainfall during Hurricane Irma, the rainy season of 2017 and the extreme rainfall event of November of 2016, it could have resulted in extreme water levels at various lagoons and the flooding of watersheds near the beaches.
- It was concluded that, surface water runoff (lagoon and ephemeral stream flows) did not contribute to beach changes when resulting from single and isolated extreme rainfall events but do result in localized beach changes when a series of extreme events combine in a relatively short time (e.g., within 1 year). The observed beach changes during the BDI can be considered typical, and attributed solely to waves, water levels and currents.

6.2.9 MEC Burial and Mobility

The beach surveys facilitated determining depths of closure and the landward limits of beach change, and the areas bounded by these. Within these areas, waves and currents, combined with beach-wide bottom changes, would increase the likelihood of MEC mobility, and depths of burial beyond the depths that could result from the interaction of MEC and waves and currents alone (Wilson et al. 2008). Seaward of the depth of closure, MEC may or may not self-bury to shallow depths (e.g., one MEC diameter) depending on the local depth, waves and

currents, and bottom characteristics. Consistent with Wilson et al. (2008) and except for extreme wave conditions, unburied MEC seaward of the depth of closure would not exhibit mobility because its weight-to-drag ratio would be higher than that of the bottom sediment, and buried MEC will remain buried.

The BDI provided insight into the potential burial and mobility of MEC within the area of beach change, and outside in the nearshore beyond the depth of closure. On this regard and pertaining to the VNTR and conditions during the BDI, the following conclusions were made:

- Depth of burial is a function of the MEC characteristics (size, weight, shape) and condition (orientation), bottom type (sand, seagrass, reef), grain size (if sandy bottom), water depth, wave conditions and beach dynamics.
- In general, MEC will remain on top of hard bottoms, remain on top or partially self-bury in seagrass bottoms, and partially or self-bury completely in sandy bottoms.
- In typical wave conditions and sandy bottoms, the tendency of MEC is to self-bury, depending on the water depth. The depth of burial depth decreases as the water depth increases.
- MEC located in areas of beach change (e.g., landward of the depth of closure) would tend to self-bury deeper (more than one diameter) due to beach-wide bottom changes.
- Except for extreme wave conditions, MEC located seaward of the depth of closure would not exhibit appreciable mobility because its weight-to-drag ratio would be higher than that of the bottom sediment, and buried MEC will remain buried.
- In areas of very fine sediment (e.g., less than 0.1 mm), relatively heavy MEC could self-bury deep (more than one diameter) due to bottom fluidization. This burial process has been described by Baeye et al. (2012), Brandes (1999), Brandes et al. (2002), Brandes et al. (2004), Plager (2000) and Richardson et al. (2001).
- In typical wave conditions, MEC at dynamic beaches will self-bury as soon as within 71 days and as late as 200 days from deployment (i.e., impact).
- In typical wave conditions, MEC at stable beaches will self-bury as soon as within 182 days and as late as 595 days from impact, or potentially never.
- The sand channel at Beach 24 appears to be a key feature for surrogate mobility at this beach, and possibly a proxy for the similar behavior of MEC at other beaches.

The wave measurements performed during the BDI were instrumental in hindcasting wave conditions at the BDI beaches and enabled the development of conceptual-level tools for the estimation of depth of burial and potential mobility of MEC. These tools provided a good indication of the burial condition, order of magnitude depth of burial of the surrogates, and the potential of the waves to bury or move the types of MEC surrogates deployed.

Among the several formulas available for the prediction of the depth of burial (Bd) (Cataño-Lopera et al. 2006, Sumer et al. 2001, and Demir et al. 2007) dependent on the Keulegan-Carpenter (KC) and Reynolds (Re) numbers or Shields parameter, the formula by Demir et al. (2007) dependent on the Shields parameter combined with the range of vertical bottom change measured at the BDI beaches, produced the best correlation between measured and predicted depths of burial. Sediment samples collected during the BDI made possible the estimation of depths of burial. In addition, the grain size data collected can be used in future studies to compute theoretical beach profiles, in sediment transport models, and to calibrate/verify models to estimate long term (e.g., years or decades) beach evolution.

At each surrogate location, water depths, sediment sizes, surrogate diameter and density were used with a wave hindcast for 2015 to derive hindcasts of enhanced bottom shear stress due to waves, and mobility parameter (MP) as defined by Friedrichs (2015). For the typical wave conditions of 2015 and the atypical condition generated by Tropical Storm Erika, averages and maxima were used with criteria for incipient burial and mobility and compared to measurements. In general, the enhanced bottom shear stress and the MP estimated well the

potential of the waves to bury and move MEC, respectively. However, discrepancies between the estimates and measurements were noted, as expected, because both assume cylinders are oriented perpendicular to the wave direction and on sandy bottoms, which are conditions different than those of the actual surrogates deployed.

The conceptual-level tools developed for the estimation of depth of burial and potential mobility of MEC could be used, together with maps of bottom structure and cover, to infer where MEC could be present, explain observations from other studies (e.g., WAA), and plan future investigations and remediation.

Furthermore, to assist future investigations, remediation, and long-term monitoring, as applicable, a wave model could be developed to hindcast waves at any location of interest in Vieques. If deemed warranted, it would be calibrated and verified using the wave measurements performed during the BDI and wave data collected from third parties. Because the wave model would be forced with regional wind and wave hindcasts spanning many years (e.g., decades), resulting local wave hindcasts and estimates of depths of burial and mobility of MEC would also span many years, would be representative of a wide range of conditions, including those not encountered during the BDI, and would allow for the analysis of impacts of past events of interest such as hurricanes.

Similarly, the long-term wave hindcasts together with water level predictions could be used with a beach evolution model to compute changes at any beach in Vieques, to analyze the impact of past events of interest such as hurricanes, and to establish landward limits of beach change and depth of closure (i.e. areas of beach change) for a wide range of conditions including extreme metocean events. The beach surveys performed during the BDI would be used for calibrating and verifying the beach evolution model.

TABLE 6-1
Summary of Beach Dynamics Results
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Coast	**South**					**East**		**North**			**West**
Beach	**1**	**2**	**3**	**4**	**19**	**12**	**14**	**5**	**22**	**24**	**SWMU 4**
Dynamics	dynamic	dynamic	stable	stable	stable	dynamic	dynamic	stable	stable	dynamic	stable
Beach Profiles [a]	1.71	0.92	0.61	0.32	0.39	2.15	2.66	0.47 to 1.2	0.8 to 1	2.46	0.60
Area of Beach Change [b]	111 to 149	66 to 82	95 to 115	28 to 38	27 to 45	89 to 114	94 to 113	16 to 47	59 to 111	23 to 120	22 to 52
Depth of Closure [c]	-3.6 to -6	-2.2 to -2.9	-1.7 to -1.9	-1.1 to -1.8	-0.9 to 1.6	-2.6 to -3.6	-2.7 to -4.3	-0.9 to -1.2	-2.0 to -3.5	-0.5 to -4.3	-1 to -2.9
Landward Limit of Beach Change [d]	1.57 (2.28)	0.95 (1.21)	0.82 (1.00)	0.9 (1.18)	0.88 (2.00)	2.13 (2.35)	3.12 (3.40)	0.83 (0.87)	1.35 (1.33)	1.81 (1.88)	0.8 to 1.3
Range of Shoreline Positions [e]	16 to 23	8 to 15	8 to 10	1.1 to 1.4	1.6 to 2.4	7 to 14.6	8.5 to 28	1.9 to 14	2.3 to 8	13 to 57	1 to 7
Sediment Transport	cross-shore	cross-shore	negligible	negligible	negligible	longshore	longshore	negligible	negligible	longshore	negligible
Wave Height [f]	0.5 to 1 (2 to 3)	0.5 to 1 (2)	< 0.5 (1.5)	< 0.5 (1)	< 0.5 (2)	1 to 1.5 (2)	0.5 to 2 (2)	< 0.5 (1)	0.5 to 1 (1.5)	0.6 to 1.2 (1.5)	< 0.5 (2)

All dimensions in meters for the BDI conditions except where noted

a. average maximum elevation change, landward or seaward of shoreline
b. width, distance from depth of closure to landward limit of beach change
c. relative to PRVD02
d. parallel to the shoreline, average elevation relative to PRVD02 (Hurricane Maria)
e. excludes headlands
f. (Hurricane Maria)

SECTION 7

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Appendix A
Wave Measurements

APPENDIX A

Wave Measurements

1. Sensors

Waves were measured with three 1 MHz acoustic wave and current (AWAC) sensors acquired from NortekUSA. The AWACs also measured currents and water levels, but these measurements were not used in the Beach Dynamics Investigation (BDI) because currents were not considered relevant due to their offshore location, and water levels were obtained from the National Oceanic and Atmospheric Administration (NOAA) stations in Esperanza and Isabel Segunda.

The AWAC is an acoustic current profiler and directional wave sensor that features four transducers. Mounted on the sea bottom, the AWAC's three slanted transducers transmit upward acoustic beams through the water column to measure current speed and direction at selected depth intervals. The central and vertically oriented transducer measures the distance to the water surface using Nortek's Acoustic Surface Tracking (AST) technology to derive wave height and period. Wave direction is computed by combining AST with orbital velocity measurements that have adaptively been sampled in a large cell located near the surface. The AWAC features a pressure sensor to measure water levels. The AWACs stored data internally and were powered by alkaline batteries housed in an external canister. **Figure A-1** shows the AWAC and dimensions. Technical specifications of the sensors are included as an attachment to this Appendix.

2. Setup

The AWACs arrived from NortekUSA factory-calibrated and including factory calibration documentation with specifications, calibration results and factory settings. However, based on a recommendation from NortekUSA, a compass calibration was performed per Nortek's AWAC Service Manual (Nortek, 2013) on all AWACs prior to deployment.

The AWAC AST v1.47.01 software developed by NortekUSA was used, first to determine and then to setup, the AWACs data collection parameters. The Deployment Planning menu contains all parameters required to specify the operation of the AWAC. **Figure A-2** shows the Standard and Advanced AWAC menus of the Deployment Planning menu, and the AWAC setup parameters.

Data collection parameters are entered on the left, and parameters that are automatically updated (as parameters on the left are changed) are displayed on the right for the battery pack/capacity, and the assumed duration and water depth of the deployment. Using the Open/Save commands in the File menu (or the corresponding toolbar buttons) the deployment parameters were saved to a file (.dep) so that they could be re-loaded when the AWACs were recovered and redeployed.

The AWACs maintenance plan consisted of recovering and redeploying the sensors approximately every 90 days to exchange battery packs, data download, biofouling cleaning, and inspection. For planning purposes and to assess the battery life, a representative water depth of 16 m was used, as well as a deployment duration of 104 days = 90 days + 2 weeks.

The AWACs were mounted on tripods on the sea bottom. The elevation of the AWAC sensor head above the bottom when mounted on the tripod was approximately 0.6 m. Considering a blanking distance of 0.4 m (vertical distance from the AWAC sensor head to the first current profile measurement cell), this resulted in a measurement distance of 15 m from the first cell to the water surface.

AWACs cannot measure current and waves simultaneously, so when a scheduling conflict between current and wave measurements exists, the wave measurement will take precedence. Waves were collected every hour (3,600 seconds), 1,200 samples at a rate of 1 Hz resulting in 20 minutes of wave data every hour. Current was setup to measure profiles every 30 minutes (1,800 seconds). However, due to the conflict with the wave

measurements performed every hour, the resulting interval for the current profile measurements was one hour (3,600 seconds) but 30 minutes (1,800 seconds) out of phase with the wave measurements. The AWAC measures the pressure and velocities at a preset rate of twice the wave sampling rate, for example 2 Hz in for the BDI deployment.

The current profile was measured in 16 cells, spaced every 1 m, along the water column from the first measurement cell to the water surface. The current data was averaged every 6 minutes (360 seconds) consistent with NOAA's Ocean Service CO-OPS specifications. The AWAC compass was updated every 30 minutes (1,800 seconds) and heading data was converted to geographic coordinates (e.g. coordinate system: ENU).

It is noted that the 16 m estimated water depth was used only for the assessment of the battery life while planning the deployment, as well as the assumed 104-day duration of the deployment. These parameters had no effect on the performance of the AWACs. For the assumed 104 days of deployment, the expected battery utilization was 95% and the memory requirement was 70.8 MB which is less than the 176 MB memory that was installed on each AWAC. The AWACs run autonomously and each was powered by 2 Alkaline battery packs with total capacity of 1,080 Wh.

Prior to deployment, AWAC work on land consisted mainly in all-around checks to ensure the AWACs were in working order, preparation of the supporting tripods to mount the AWACs, attaching the external battery canisters, ballast weights to prevent tripod movement in storm conditions, and an acoustic transmitter to assist with searching. Biofouling was a concern and this was minimized by applying, not only prior to the first deployment, but before every redeployment that followed, a mixture of diaper cream and cayenne pepper to the AWACs and transducers.

3. Deployment

The AWACs were installed by munitions, construction, and scientific divers on Sea Spider tripods, fabricated by Teledyne Oceanscience, on the seafloor at the selected locations. The tripods are made of glass reinforced plastic and feature 3 lifting eyes, a gimbal to attach and align the AWAC, and a mounting plate to support the external aluminum battery canister. The battery canisters were wrapped in duct tape to minimize biofouling. The tripods were ballasted with 100-lbs weights on each leg and a short chain and small boat anchor was attached to one leg of the tripods for additional safety. An acoustic transmitter was attached to each tripod to assist with the search of the sensors during the BDI. **Figure A-3** shows AWAC-S before deployment and **Figure A-4** shows AWAC-E after deployment.

For each AWAC, the deployment crew navigated to the selected location and divers verified bottom conditions. If water depth and/or bottom conditions were not as planned (e.g., MEC present, potential environmental damage, or not sandy, flat, and leveled bottom), a new location within an approximately 50 m radius was selected. **Table A-1** lists AWAC coordinates (surveyed with RTK GPS), elevation (depth, surveyed with single-beam echo sounder), date/time of first deployment and acoustic transmitter characteristics (e.g., tag number, model, code, and frequency). **Figure A-5 to Figure A-7** show the locations, nearby BDI beaches and depth contours of AWAC-N, AWAC-E, and AWAC-S, respectively.

Table A-1. Coordinates, Elevations of AWACs, First Deployment Date/Time, Acoustic Transmitter Characteristics

Sensor	Easting	Northing	Elevation	First Deployment	Acoustic Transmitter
AWAC-N	253,777	2,009,123	-16.5	10/16/14 15:20	#112 EMT-01-2 code 6-6-7, freq. 75 kHz
AWAC-E	259,627	2,007,921	-12.8	10/16/14 14:25	#113 EMT-01-2 code 3-3-4-6, freq. 76 kHz
AWAC-S	257,439	2,003,758	-17.4	10/16/14 11:15	#92 EMT-01-2 code 3-6-4-8, freq. 70 kHz

Coordinates in m, Universal Transverse Mercator (UTM) 20 N NAD83
Elevations (depth surveyed) in meters (m), Puerto Rico Vertical Datum 2002 (PRVD02)
Acoustic transmitter made by Sonotronics, Inc.

kHz = kilohertz

4. Maintenance

AWAC maintenance was performed at approximately 3-month intervals. The AWAC maintenance crew navigated to the AWAC locations, commercial divers removed the sensors and battery canisters from the tripods leaving these in place, and the AWACs were brought to Camp Garcia. At Camp Garcia, the AWACs were inspected, cleaned, anti-fouling mixture applied, batteries exchanged, and setup for redeployment. Recorded data was downloaded to a laptop computer and uploaded to a server for analysis. Subsequently, the AWACs were redeployed by commercial divers. **Table A-2** summarizes the AWAC deployment and recovery dates.

Table A-2. Summary of AWAC Deployment and Recovery Dates

Activity	AWAC-N	AWAC-E	AWAC-S
1st Deployment	10/16/2014	10/16/2014	10/16/2014
Recovery	3/23/2015	3/23/2015	3/23/2015
2nd Deployment	3/26/2015	3/25/2015	3/26/2015
Recovery	7/20/2015	7/20/2015	7/21/2015
3rd Deployment	7/22/2015	7/22/2015	7/22/2015
Recovery	12/1/2015	12/1/2015	12/2/2015
4th Deployment	12/2/2015	12/2/2015	12/3/2015
Recovery	4/4/2016	4/4/2016	4/4/2016
5th Deployment	4/6/2016	4/6/2016	4/6/2016
Recovery	6/20/2016	6/23/2016	6/21/2016
6th Deployment	6/21/2016	Damaged, not deployed	6/22/2016*
Recovery	12/14/2016		12/14/2016*

* malfunctioned, did not record data

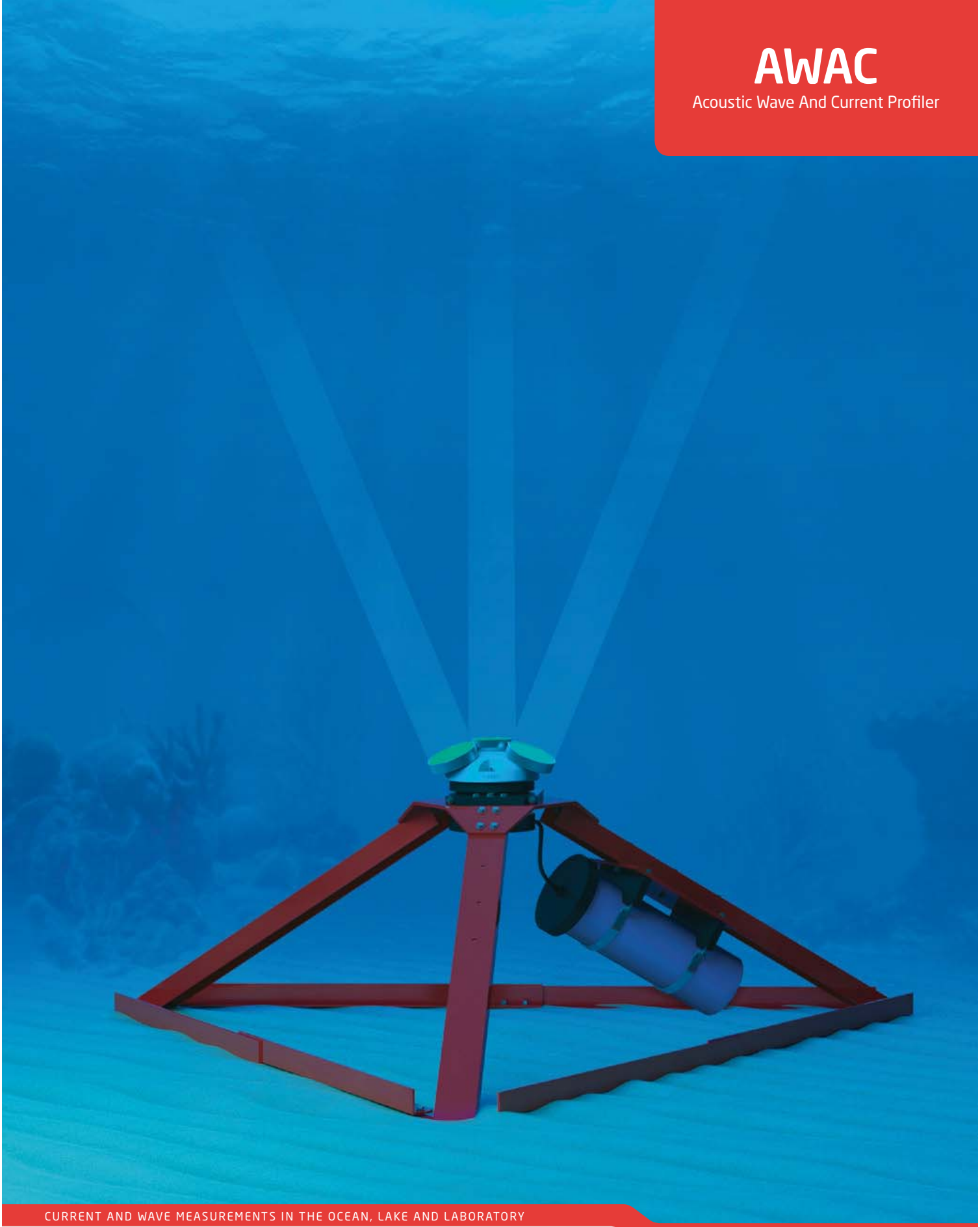
5. References

Nortek. 2013. *Service Manual*. December.

Attachment

AWAC

Acoustic Wave And Current Profiler



CURRENT AND WAVE MEASUREMENTS IN THE OCEAN, LAKE AND LABORATORY

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True innovation makes a difference

AWAC

A STANDARD IN OCEAN WAVE MEASUREMENTS

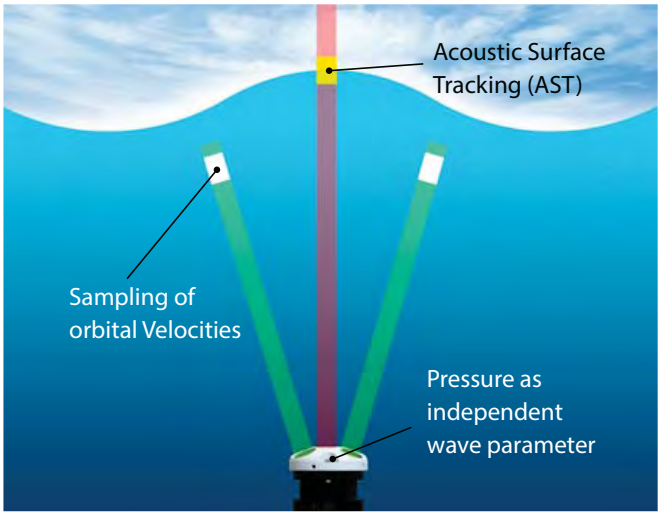
The Nortek Acoustic Waves and Currents (AWAC) sensor is a current profiler and directional wave system in one unit. Nortek has shipped more than 1700 AWACs worldwide since the launch of the first generation unit over a decade ago. The instrument has since revolutionized subsurface wave measurements.

The AWAC is well suited for both autonomous data collection and as part of a real-time data telemetry system. Subsurface deployment means the instrument is always protected from harsh weather, vandalism, and ship traffic. The small, yet rugged instrument is suitable for multi-year operation in tough environments. Plastic and titanium parts avoid corrosion. The AWAC is available in three transmit frequencies for operational ranges spanning 2m to 100m.

Trusted Wave Measurements

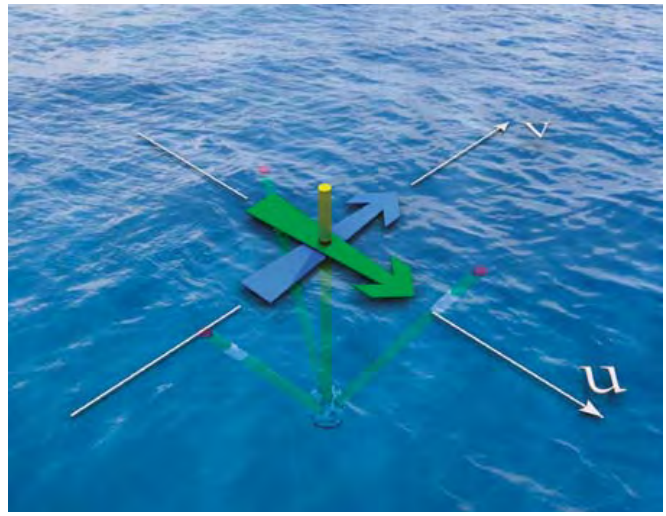
- The AWAC is in use for online and stand-alone applications all over the world. In Europe, researchers have employed dozens of AWACs to evaluate and improve coastal wave models. In Asia, port and harbor authorities trust AWACs to survive and provide excellent data during typhoon conditions. The AWAC has become a reference system for wave measurements after numerous meticulous comparisons with buoys.
- Nortek provides the AWAC as part of a turnkey solution for long-term monitoring. This includes durable connectors and long cables, integrated acoustic modems, a verified internal wave processor, and online processing and data display software.
- The AWAC of today has seen over a decade of development, continually being optimized with enhanced features. These include rapid pinging, narrow acoustic beams to provide the best time and space resolution, adaptive tracking algorithms to accommodate large variations in depth and low power consumption for long endurance deployments.
- The AWAC can be mounted in subsurface buoys to add wave measurements to long moorings or to avoid burial and excessive tilt in soft sediments. Nortek's validated and patented SUV technology (US patent 7,352,651) makes accurate wave measurements and high resolution surface currents attainable in deep water as well as areas with uncertain bottom conditions.

Wave Height



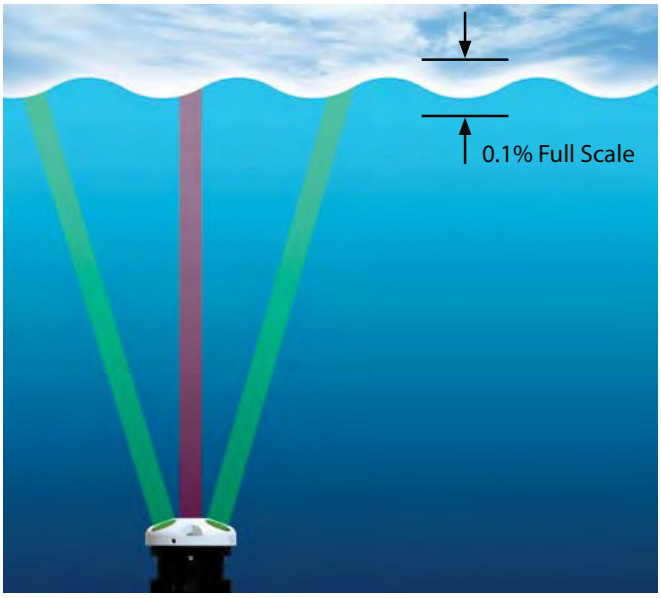
The AWACs extraordinary wave height measurements are a result of the extensively validated and optimized Acoustic Surface Tracking (AST) algorithms. AST estimates the distance to the surface by echo-ranging with the vertically oriented transducer. This method circumvents the depth limitations imposed by bottom mounted pressure and velocity measurements and allows the instrument to capture 1 to 50 second period waves. Moreover, AST gives you the ability to derive wave parameters based on times series analyses such as Hmax, H1/10, and Tmean. Time series analysis is included in the Nortek wave processing software.

Wave Direction



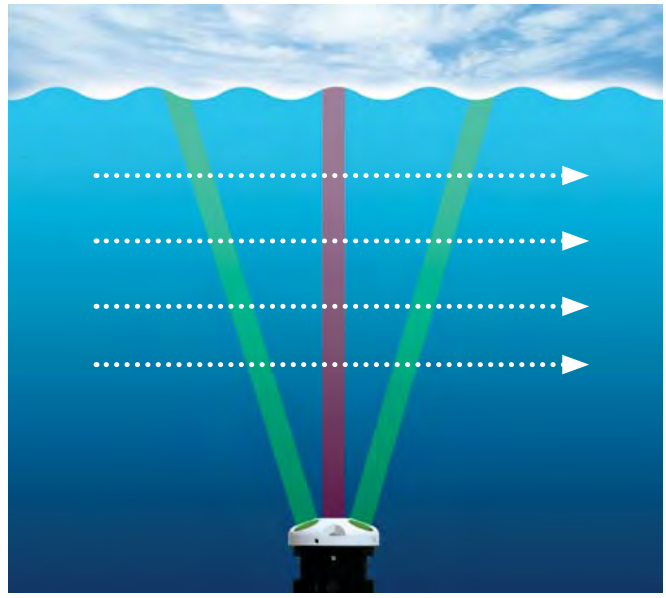
Wave direction is calculated by combining AST with orbital velocity measurements that have adaptively been sampled in a large cell located near the surface. If the AWAC is mounted in a non-moving frame or structure, Nortek uses the maximum likelihood method applied to the three velocities and the surface position to estimate all directional wave parameters and spectra. and spread. Nortek's patented SUV processing can be used to calculate all the same directional estimates from an AWAC on a subsurface buoy.

Tidal Elevation



The AWAC pressure data are suitable for measuring the tidal elevation from a fixed bottom mounted structure. Nortek recently extended the option to upgrade the AWAC pressure sensor to an absolute accuracy of 0.1% of full scale, or 5 cm for a 50 m sensor. This pressure sensor is temperature compensated and the tidal changes only span a small portion of the full-scale range. Therefore, accuracy of the change in tidal elevation is normally twice that of the absolute accuracy, or around 2.5 cm for a 50 sensor.

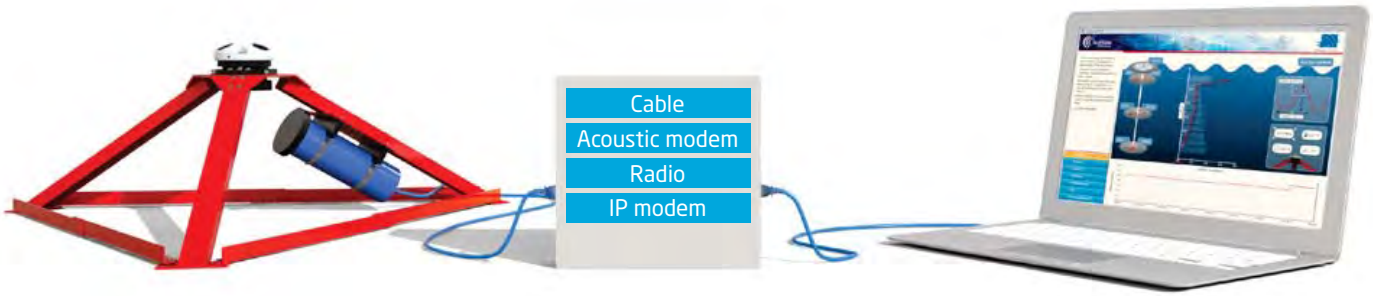
Current Profile



The AWAC uses the three slanted beams to measure the current profile over a range determined by the acoustic frequency. Large transducers transmit narrow acoustic beams and provide accurate data. The AWAC will alternate between wave data collection and current profiling. If the wave data collection is longer than the interval between current profiles, the AWAC will skip a current profile to ensure continuous wave data. Please contact Nortek if concurrent wave and current information is required.

Real-Time Data Collection

Most Nortek products can be used either in stand-alone or online mode. In stand-alone mode, data is collected to the internal recorder, and the power comes from external batteries. In an online system, data are transferred to a shore station using one or more communication links.



- **Cables:** Nortek provides rugged polyurethane cables with optional titanium connectors. Data may be transferred over cables of up to 5000m. An interface box installed on shore protects the AWAC from surges and converts the supply voltage to 48V. A DCDC converter in the instrument reduces the voltage back to 15V.

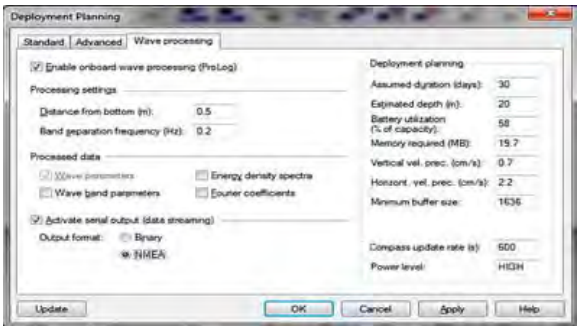
- **Acoustic modems:** In combination with the ProLog internal processor, it is possible to transfer wave and current data over short distances underwater using acoustic modems provided by Nortek.

- **Radio and IP modems:** Radio communication relies on line-of-sight and can be used to transfer AWAC data from an offshore buoy to shore or from a point along the coast further inland. In areas with adequate cellular communication, IP modems may be used to transfer data.

- **AOS:** It is possible to integrate the AWAC with the Nortek Autonomous Online System and view the resulting data in a hosted web environment.

ProLog

The ProLog consists of a powerful processor and a 4 GB SD-card recorder laid out on a separate circuit board that fits inside the AWAC. The processor takes the raw data from the AWAC, runs the directional wave processing algorithms and outputs the processed data in ASCII (NMEA) or binary format. This makes the ProLog ideally suited for online applications where data transfer rates are limited, as when using acoustic modems or satellites. The NMEA format also facilitates the integration of the AWAC with 3rd party external controllers.



Nortek offers a full suite of software with the AWAC

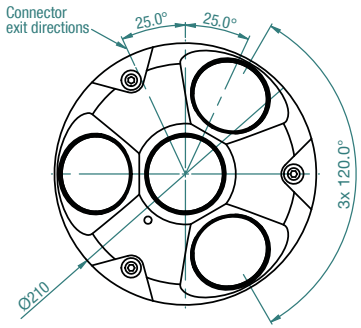
AWAC-AST is included with all AWAC deliveries. It features a simple interface used to configure the instrument for deployment, retrieve the data, and convert the raw data to ASCII.

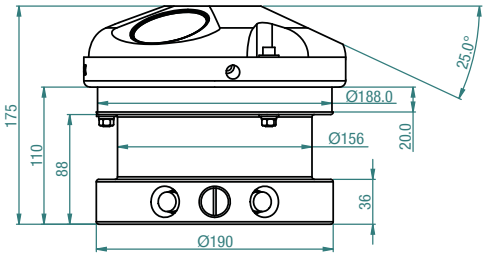
Quickwave provides the functionality of Storm in a non-graphical environment. A wave processing module embedded in a DLL is available for those who wish to write their own real time software.»

Storm provides a full graphical interface to view the raw wave data and current profiles, perform QA/QC, and plot the directional and non-directional wave parameters.

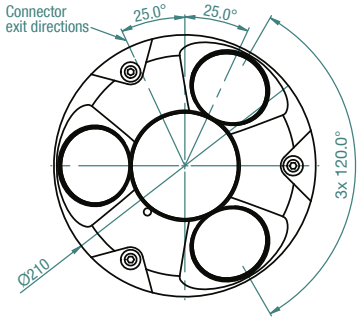
SeaState is designed for configurations where there is direct communication. It collects, processes, records and displays data in real-time as a series of graphical images, which are suitable both for engineering and scientific applications. SeaState accepts both raw data and processed wave data from a ProLog internal processor.

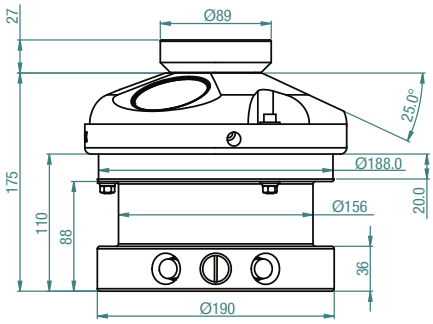
1MHz



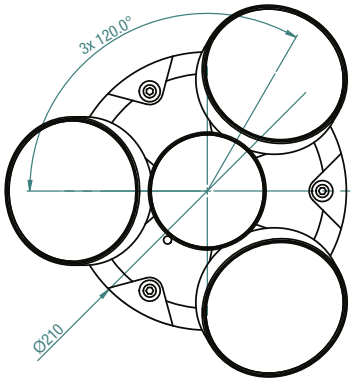


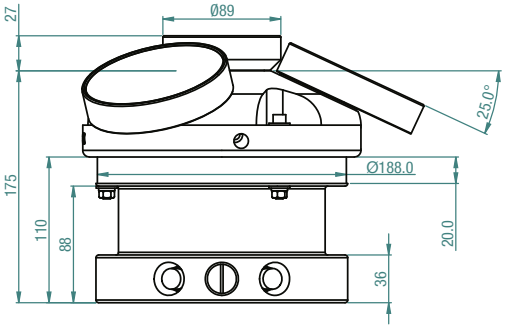
600kHz





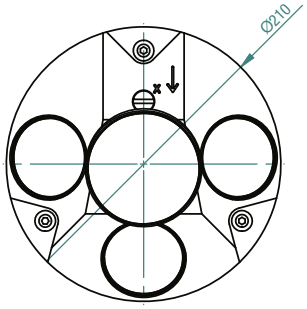
400kHz

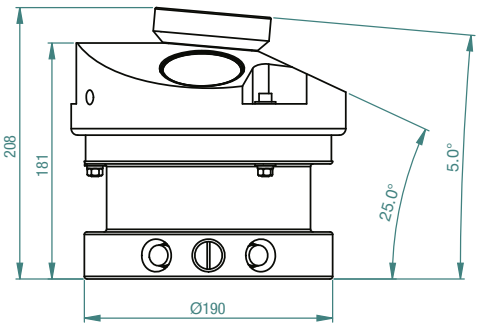




Platform Mount (1MHz and 600kHz)

Contact Nortek for additional transducer configuration options designed to mount on coastal, offshore, or marine renewable energy structures.





All dimensions in mm.

Technical Specifications

System	
Acoustic frequency:	1MHz, 600kHz or 400kHz
Acoustic beams:	4 beams, one vertical, three slanted at 25°
Vertical beam opening angle:	1.7°
Operational modes:	Stand-alone or online monitoring
Current Profile	
Maximum range:	30m (1MHz), 50m (600 kHz), 100m (400kHz)*
Depth cell size:	0.25 – 4.0m (1MHz) 0.5 – 8.0m (600kHz) 1.0 – 8.0m (400kHz)
Number of cells:	Typical 20–40, max. 128
Maximum output rate:	1Hz
*)depends on local conditions	
Velocity measurements	
Velocity range:	±10 m/s horizontal, ±5 m/s along beam
Accuracy:	1% of measured value ±0.5 cm/s
Doppler uncertainty	
Current profile:	1cm/s (typical)
Wave measurements	
Maximum depth:	35m (1MHz), 60m (600 kHz), 100m (400kHz)
Data types:	Pressure, one velocity along each beam, AST*
Sampling rate (output):	2 Hz velocity, 4 Hz AST* (1MHz), 1 Hz velocity, 2Hz AST* (600kHz), 0.75 Hz velocity, 1.5Hz AST* (400kHz)
No. of samples per burst:	512, 1024, or 2048. Inquire for options
Wave estimates	
Range:	-15 to +15m
Accuracy/resolution (Hs):	<1% of measured value/1cm
Accuracy/resolution (Dir):	2º / 0.1º
Period range:	0.5 - 50s (1MHz), 1 - 50s (0.6MHz), 1.5 - 50s (0.4MHz)

Depth(m)	cut-off period (Hs)	cut-off period (dir)
5	0.5 sec	1.5 sec
20	0.9 sec	3.1 sec
60	1.5 sec	4.2 sec
100	2 sec	5.0 sec

Sensors	
Temperature:	Thermistor embedded in housing
Range:	–4°C to 40°C
Accuracy/ Resolution:	0.1°C/0.01°C
Time constant:	<5 min
Compass	Magnetoresistive
Accuracy/Resolution:	2°/0.1° for tilt <15°
Tilt:	Liquid level
Maximum tilt:	30°, AST* requires <10° instrument tilt
Up or down:	Automatic detect
Pressure:	Piezoresistive
Standard range:	0–50 m (1MHz) / 0-100m (0.6MHz) / 0-100m (0,4MHz)
Accuracy:	0.5% of full scale. Optional 0.1% of full scale.
Resolution:	0.005% of full scale
Transducer configurations	
Standard:	3 beams 120º apart, one vertical
Platform mount:	3 beams 90º apart, one at 5°
Materials	
Standard:	Delrin and polyurethane plastics with titanium screws
Connectors:	
Bulkhead (Impulse):	MCBH-2-FS, MCBH-8-FS, optional Birns 3K-7-OR-CA
Cable:	PMCIL-8-MP, Optional Birns

Environmental	
Operating temperature:	–4°C to 40°C
Storage temperature:	–20°C to 60°C
Shock and vibration:	IEC 721–3–2
Depth rating:	300m
Dimensions:	
	See drawing
Weight in air:	7.3 kg (0.4MHz), 6.2 kg (0.6MHz), 6.1 kg (1MHz)
Weight in water:	3.6 kg (0.4MHz), 2.9 kg (0.6MHz & 1MHz)
Canister for 2*36D pack with Alkaline batteries:	In air 17,2kg, in water 7,8kg
Canister for 2*36D pack with Lithium batteries:	In air 14,4kg, in water 5kg
Canister for 1*36D pack with Alkaline batteries:	In air 10,5kg, in water 4,3kg
Canister for 1*36D pack with Lithium batteries:	In air 9,1kg, in water 2,9kg
Analog Inputs	
Number of channels:	2
Supply voltage to analog output devices:	Three options selectable through firmware commands: • Battery voltage/500mA • +5V/250mA (default) • +12V/100mA
Voltage Input:	0-5V
Resolution:	16 bit A/D
Data Recording	
Capacity(standard):	9MB (standard), 4GB upgrade option
Profile record:	Ncells×9 + 120
Wave record:	Nsamples×24 + 1KB
Data Communication	
I/O:	RS 232 or RS 422
Communication baud rate:	300–115200
Recorder download baud rate:	600/1200 kBaud for both RS232 and RS422
User control:	Handled via «AWAC» software, or ActiveX® controls. «SeaState» for online systems.
Output formats:	Output formats: NMEA, Binary. Prolog provides same types also for processed wave and current data.
Power	
DC input:	9-18 VDC
Peak current:	3A
Power consumption:	Transmit power: 1–30W, 3 adjustable levels
Sleep consumption:	1 mW (RS232) 5 mW (RS422)
Real time clock	
Accuracy:	± 1min/year
Backup in absence of power:	1 year

Online Cable

Polyurethane jacket, Shore D hardness, 13mm in diameter. Maximum RS422 communication distance 5km when used with interface box.

Online Projects

Nortek can provide long cables, radio/telephone communication equipment, acoustic modems, etc., that can meet the requirements of your specific project.

*) AST = Acoustic Surface Tracking

TS-010-en-10.2014

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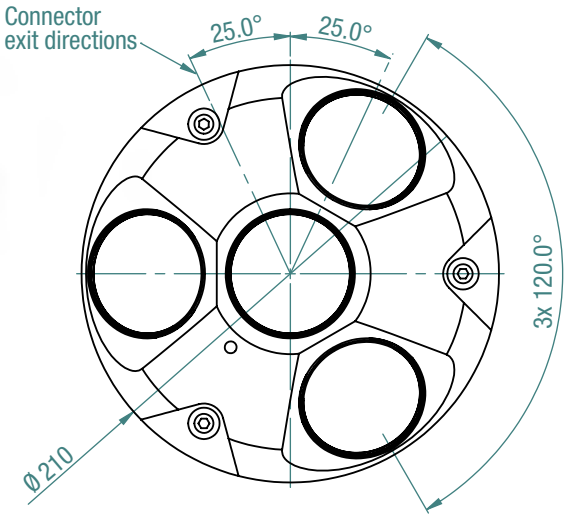
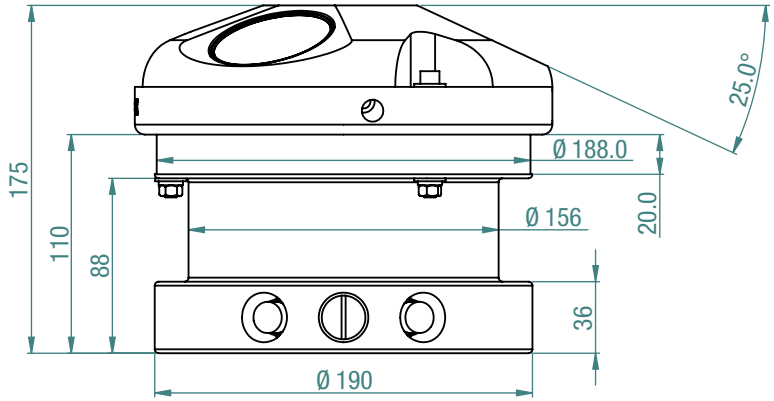
Figures

1MHz



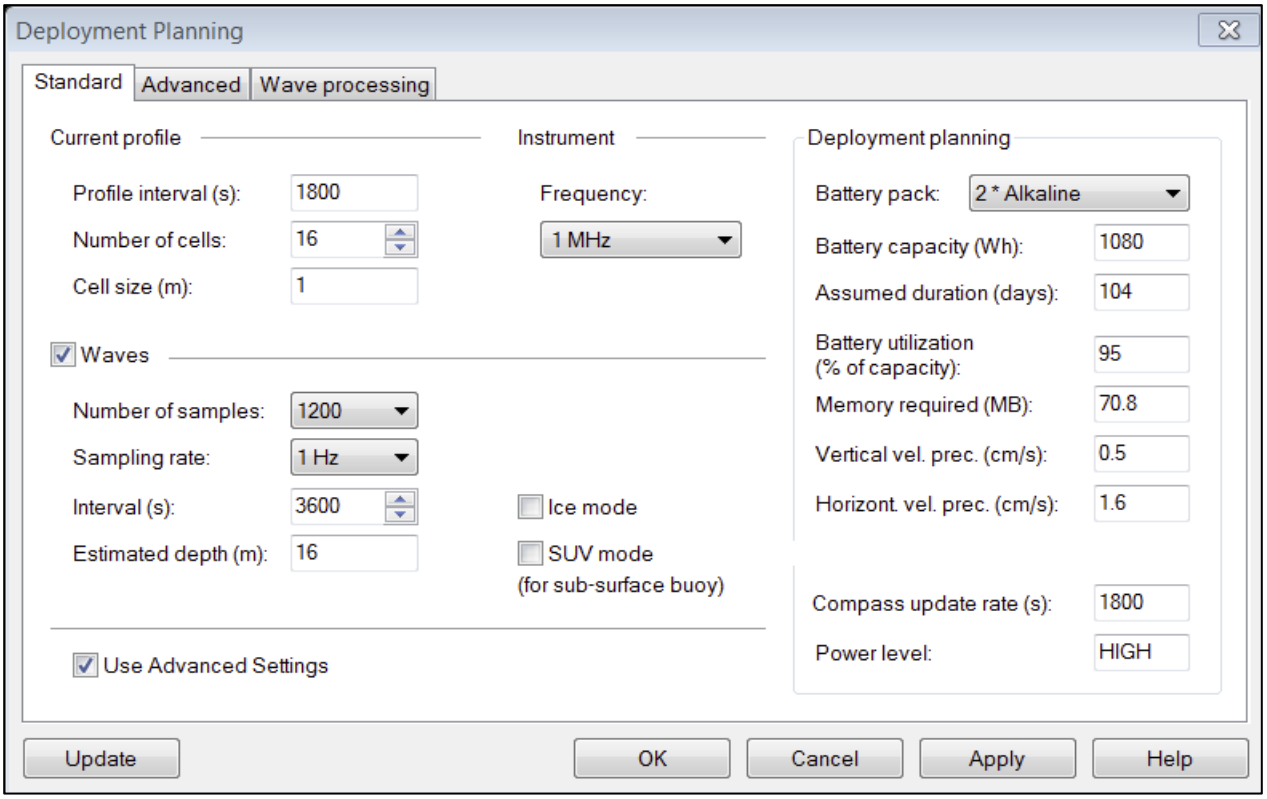


NOTES

1. Sensor image and specifications from Nortek AS, 2017.
2. All measurements in millimeters.

FIGURE A-1
Nortek 1 MHz Acoustic Wave and Current (AWAC) Sensor
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Standard



Advanced

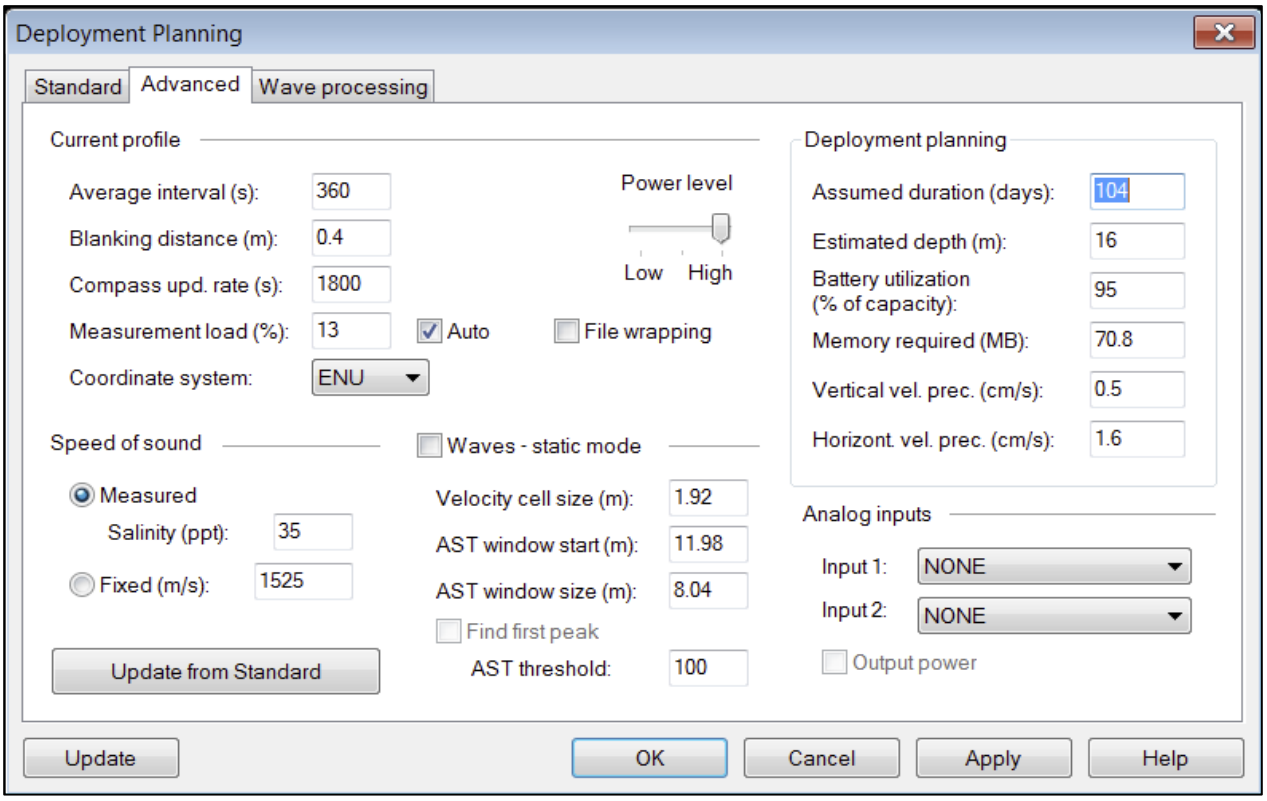


FIGURE A-2
AWAC Standard and Advanced Wave and Current Settings, and Estimate of Battery Capacity and Memory
Beach Dynamics Investigation Report
Vieques, Puerto Rico

FIGURE A-3
AWAC-S Before Deployment
Beach Dynamics Investigation Report
Vieques, Puerto Rico

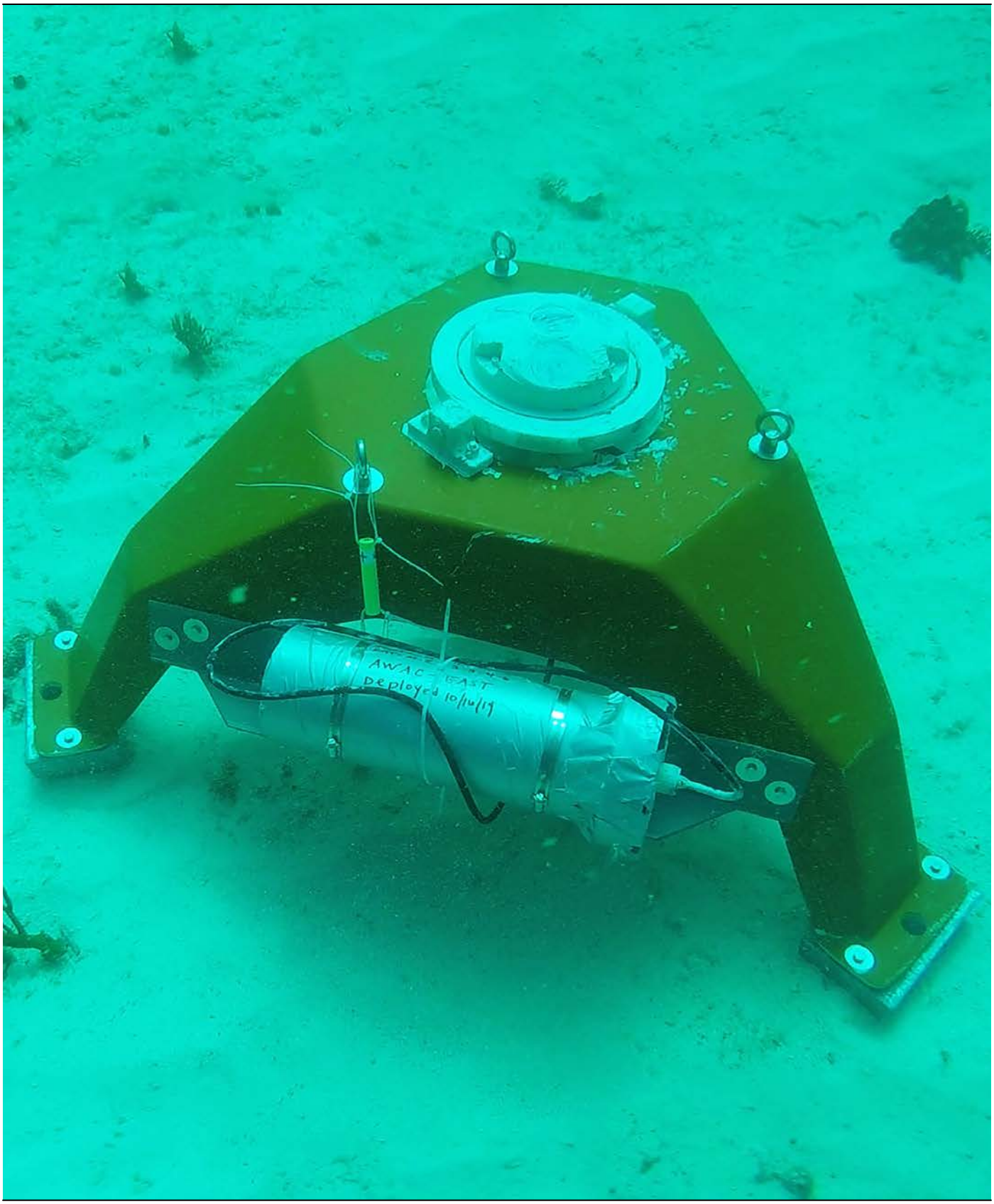


FIGURE A-4
AWAC-E After Deployment
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2017 Google Earth. Image 2017 U.S. Geological Survey.

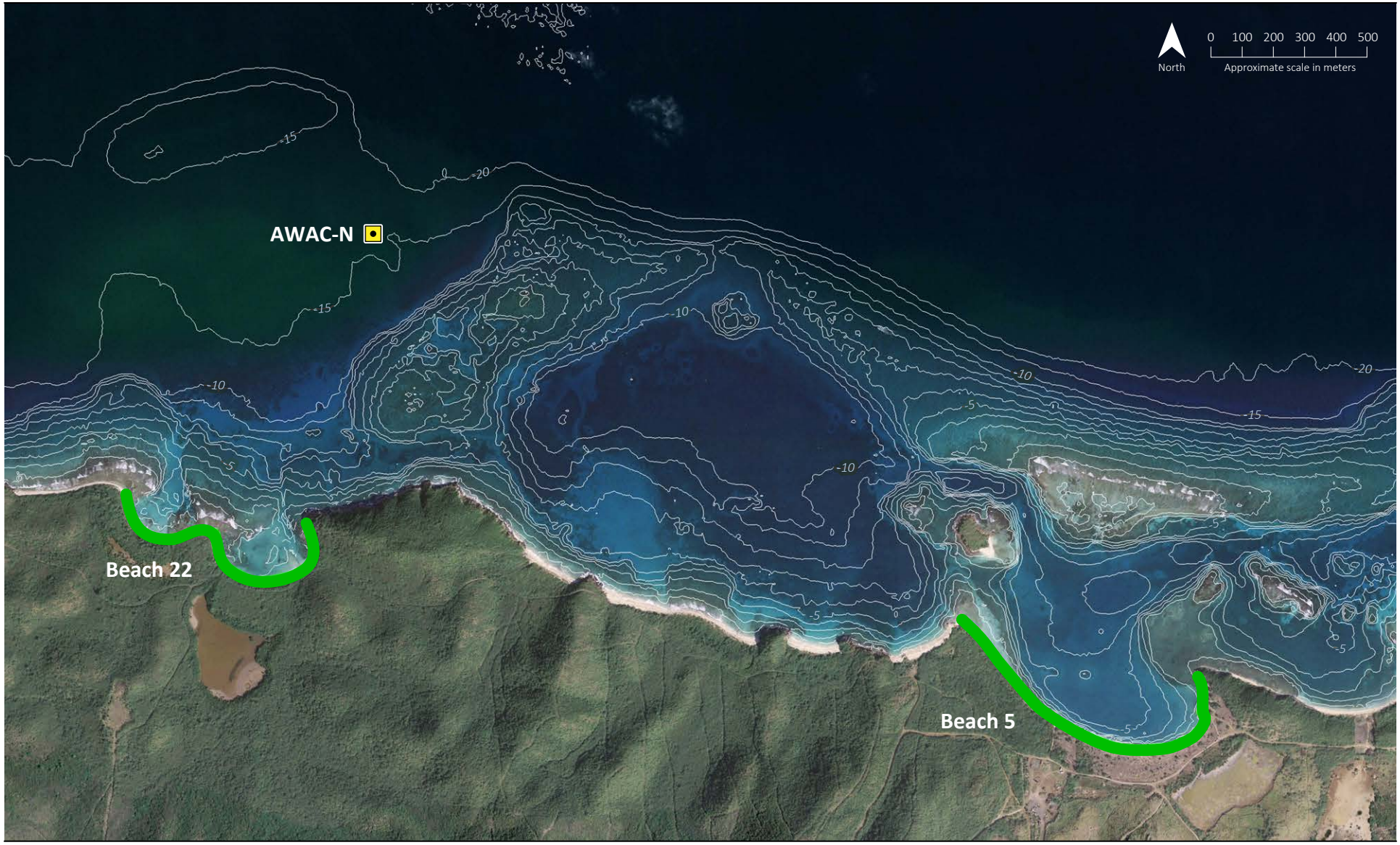


FIGURE A-5
AWAC-N Deployment Location, Nearby BDI Beaches, and Depth Contours (m, PRVD02)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2017 Google Earth. Image 2017 U.S. Geological Survey.

FIGURE A-6
AWAC-E Deployment Location, Nearby BDI Beaches, and Depth Contours (m, PRVD02)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2017 Google Earth. Image 2017 U.S. Geological Survey.

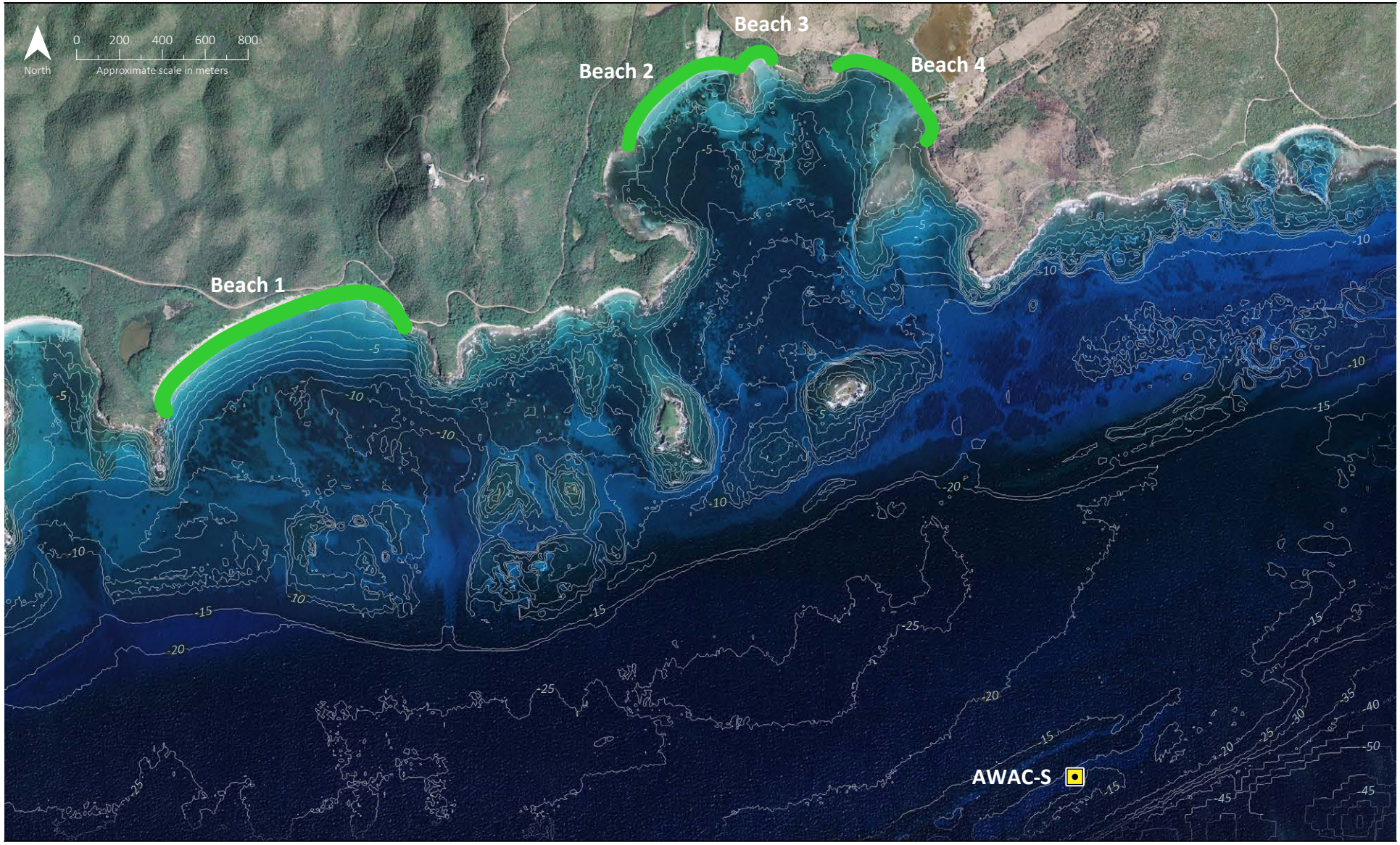


FIGURE A-7
AWAC-S Deployment Location, Nearby BDI Beaches, and Depth Contours (m, PRVD02)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Appendix B
Rainfall Measurements

IV SPECIFICATION

Receiver: 200 mm ± 0.3 diameter heavy duty cast aluminium, Powder coated.

Bucket capacity: Plastic: 0.2 mm, 0.5 mm, 0.01 inch of rainfall.
Metal: 1.0 mm of rainfall

Sensitivity: one tip.

Maximum intensity: 700 mm / hr.

Calibration accuracy:

TB4 bucket capacity	Measuring range	Accuracy
0.1mm, 0.2mm, 0.01" & 1.0 mm	0-250mm/hr	± 2 %
	250-500mm/hr	± 3 %

Long term stable calibration.

Humidity: 0 to 100 %

Temperature: - 20 to +70˚C

Contact system: dual reed switches potted in soft silicon rubber with varistor protection.
- -Max Capacity: 0.5 amp, 12 Volts D.C.
- - Resistance: Initial contact resistance 0.1 OHMS
- - M.T.B.F: 10^8 to 10^9 Operations

Syphon: 0.4 mm (12ml) capacity of rainfall - made from brass with a non hydroscopic outer case. The syphon can be dismantled for routine cleaning and servicing.

Bucket: Two types of buckets, synthetic ceramic coated brass bucket balanced to + 0.05 gms for 1mm bucket only, and injection moulded non hydroscopic plastic ABS chrome plated UV stabilised balanced + 0.05gms for 0.2mm, 0.5mm and 0.01".

Base: injection moulded non-hydroscopic ABS plastic UV stabilised.

Level: bulls eye level fitted to base.

Mounting holes: three 10 mm diameter mounting holes at 234 mm PCD in feet moulded to outside diameter of base.

Drain fittings: to attach 12 mm inside diameter tubing, to catch rainfall after passing through buckets.

Bucket pivot system: two stainless spring steel rolling bearings, clamped at 90 degrees to bucket stainless spring steel axle.

Insect covers: stainless steel mesh on all openings to prevent insects and ants entering gauge.

Outer enclosure:	keyed to enable the release of the outer enclosure without the need for the removal of the three securing screws.
Height:	315mm
Weight:	2 kg
Packed Dimensions:	3 kg 0.03m^3

V INSTALLATION

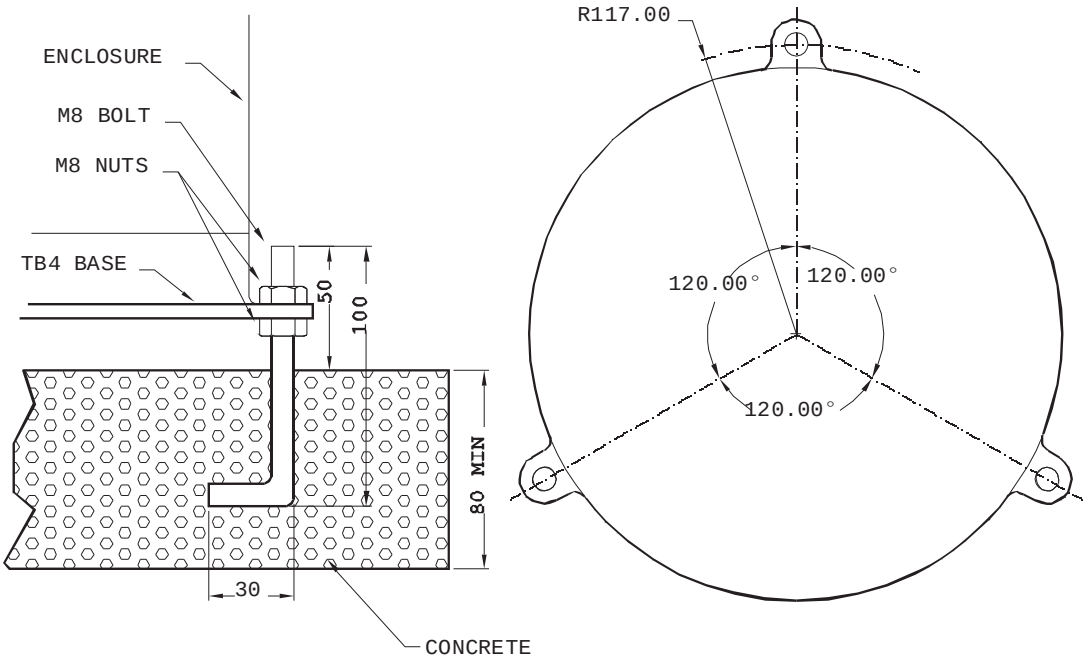


DIAGRAM 1

(i) Site Selection

Rainfall measurements are intended to be representative of the actual rain falling on a given area. Some of the more important factors which influence the representativeness of a gauge are as follows:

- Site the gauge on level ground where possible. Avoid sloping sites.
- Site should have adequate protection from strong winds.
- Site should be free of large obstructions such as buildings and trees.
- Provide suitable ground surface to avoid splashing into the gauge.

(ii) Setting up

- Install the gauge on the foundation. A suggested foundation is shows in Diagram 1.
- Loosen the three enclosure securing screws and the enclosure.
- The gauge is provided with a bull's eye level. Adjust the nuts on mounting bolts until gauge is level.
- Connect lead to the raingauge terminals, refer to Diagram 3 page 9, and to the recording device, in accordance with manufacturer's instructions.

VI TEST OPERATION

- Manually tip the bucket a number of times, ensuring that each tip is being recorded and that the tilting mechanism is operating freely.
- Replace and secure the enclosure.

Appendix C
Coordinate System and Benchmark Network

APPENDIX C

Coordinate System and Benchmark Network

The coordinate system adopted for the Beach Dynamics Investigation (BDI) was the Universal Transverse Mercator (UTM) Zone 20 N in meters (m), and the vertical datum Puerto Rico Vertical Datum 2002 (PRVD02). According to water level datum at National Oceanic and Atmospheric Administration (NOAA) Station 9752695 Esperanza, PRVD02 is 0.02 m below the mean sea level (MSL). Given this relatively small discrepancy and for convenience, the elevations at the PRVD02 can be interpreted as elevations relative to the MSL.

A benchmark network was setup to achieve the accurate survey of beach profiles, and location of sediment samples, munitions and explosives of concern (MEC) surrogates, and metocean sensors that the BDI required. The BDI used Real Time Kinetic (RTK) global positioning system (GPS) technology by which, prior to any survey activity, a base receiver was installed at a benchmark at the top of Cerro Matias Jalobre (also known as Observation Post 1 or OP1), and rover receivers were used for both the land and water surveys. The base receiver at the OP1 benchmark transmitted correction signals in real time to the rover receivers via a UHF radio link to achieve centimeter (cm)-level horizontal and vertical position accuracy. Without this correction, non-RTK positioning would be in the order of meters. The benchmark network consisted of the OP1 benchmark and several control benchmarks at the BDI beaches and other locations of interest. The network allowed for the quick verification of the acquired position and accuracy of the rover receivers before any survey was performed.

The first step in the setup of the benchmark network was the verification of the OP1 benchmark coordinates and elevation given that these would be used as reference. Taken from the ECLS (2012) report, these were established (tied, referenced to) using the National Geodetic Survey (NGS) 2695A benchmark at the NOAA tide station in Esperanza. On March 19, 2015, the GPS base receiver was setup at the OP1 benchmark with the following parameters:

Universal Transverse Mercator (UTM) Zone 20 N m
NAD83 CONUS MOL
GEOID12A

Easting	254,863.77 m (per ECLS, 2012)
Northing	2,006,232.09 m (per ECLS, 2012)
Elevation	133.4 m PRVD02 (per ECLS, 2012)

The coordinates and elevation of benchmark 2695A at Esperanza were checked with a rover receiver. The eastings and northing obtained for benchmark 2695A were compared against those reported in ECLS (2012) and the elevation was compared against that reported in the 2965A benchmark data sheet. A discrepancy of 0.026 m in the easting and 0.055 m in the northing was noted. Considering that OP1 (and the GPS base receiver) is approximately 17 kilometers (km) from Esperanza these discrepancies were considered acceptable, and the horizontal coordinates of the OP1 benchmark given by ECLS (2012) were also considered sufficiently accurate for purposes of the BDI. However, the elevation of benchmark 2695A measured with the GPS rover receiver was 1.461 m PRVD02, resulting in a 0.501 m difference (low) relative to the elevation of benchmark 2695A at 1.962 m PRVD02 in the 2965A benchmark data sheet. The elevation of the water surface was measured from benchmark 2695A and the difference with the reported NOAA water level was 0.002 m, indicating that water levels reported by NOAA and the elevation reported in the NGS data sheet for benchmark 2695A were correct. The NGS 2965A benchmark data sheet is included as an attachment to this Appendix.

While performing the check at Esperanza, the GPS base receiver collected satellite data for approximately 5 hours to assist in the verification of the elevation the OP1 benchmark. The data were subsequently analyzed with the NGS's Online Positioning User Service (OPUS) which provides simple access to high-accuracy National Spatial Reference System (NSRS) coordinates. The data file collected was uploaded to and analyzed by the service.

OPUS reported the following elevations:

Ellipsoid Height (h)	91.907 m
Orthometric Height (H)	133.96 m (GEOID12A same as PRVD02)

The orthometric height (H) was independently verified using the ellipsoid height (h) reported by OPUS and the GEOID12A elevation (N) computed with an NGS online utility for the OP1 location; H = h – N = 91.907 – (-42.053) = 133.96 m. This result indicated that the elevation of the OP1 benchmark reported by ECLS (2012) was indeed low.

On March 25, 2015, to verify the revised elevation of the OP1 benchmark, the GPS base receiver was setup at the OP1 benchmark with the following parameters:

UTM Zone 20 N m
NAD83 CONUS MOL
GEOID12A

Easting	254,863.77 m (per ECLS, 2012)
Northing	2,006,232.09 m (per ECLS, 2012)
Elevation	133.96 m PRVD02 (per OPUS of March 19, 2015)

The elevation of benchmark 2695A was measured twice at 2.041 and 2.051 m PRVD02, which resulted in discrepancies of 0.08 m and 0.09 m (high) relative to benchmark 2695A's 1.962 m PRVD02 elevation. Measured eastings and northing were compared against benchmark 2695A's ECLS (2012) coordinates, and discrepancies of 0.006 to 0.02 m in the easting and 0.06 to 0.065 m in the northing were observed. These are considered acceptable considering that the GPS base receiver was located 17 km away from Esperanza.

Once the OP1 benchmark was accurately located, control benchmarks were identified and installed at various locations such as OP1, Camp Garcia and Mount Pirata, and at all the BDI beaches. **Figure C-1** shows the GPS base receiver installed at the OP1 benchmark, and control benchmark Beach 5–B. **Table C-1** lists all benchmarks that composed the BDI benchmark network.

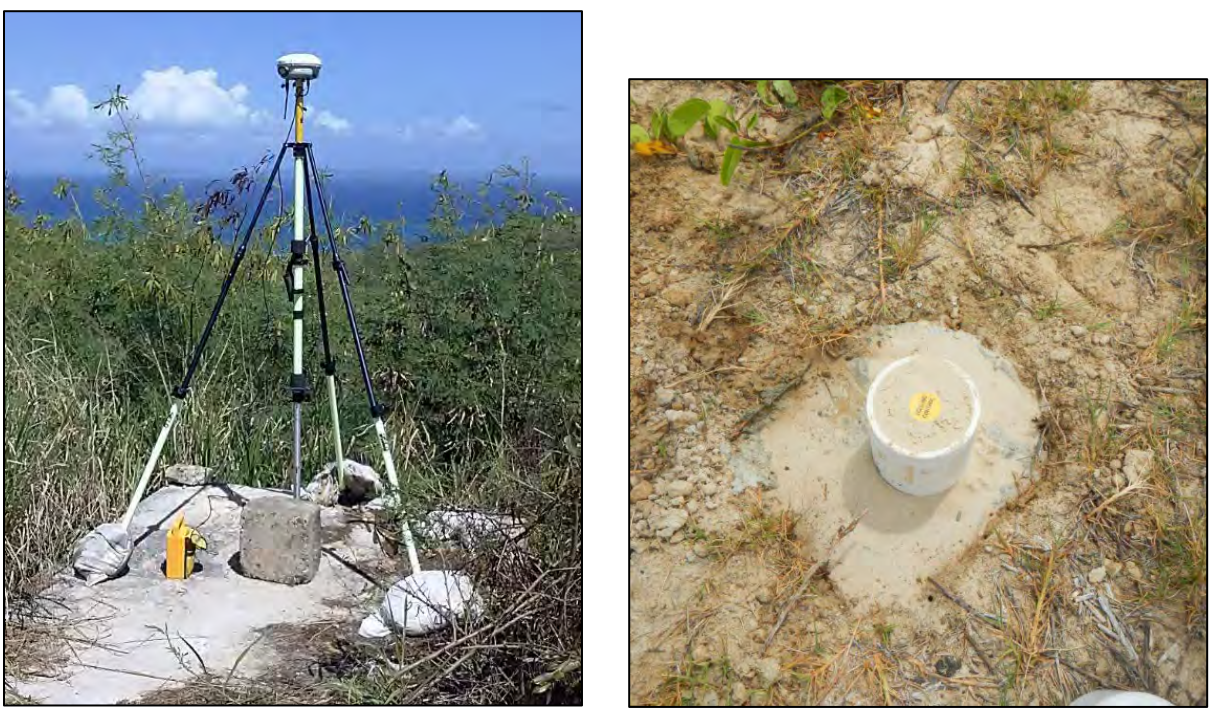


Figure C-1. GPS Base Receiver Installed at the OP1 Benchmark (left), Control Benchmark Beach 5-B (right)

Table C-1. Location and Elevation of BDI Benchmarks

Benchmark	Easting (m)	Northing (m)	Elevation (m, PRVD02)
OP1 BASE	254863.77	2006232.09	133.96
OP1 CONTROL	254,843.54	2,006,242.52	134.13
Camp Garcia Rebar	244,391.65	2,005,195.83	20.459
Camp Garcia X	244,375.01	2,005,186.59	20.256
Mt. Pirata BASE	229,996.70	2,002,411.55	291.428
Mt. Pirata CONTROL	230,003.01	2,002,422.01	291.166
NOAA Esperanza	238,448.31	2,002,321.35	1.962
Beach 1-A	253,994.37	2,005,688.50	7.615
Beach 1-B	253,998.12	2,005,721.00	9.954
Beach 2-A	255,908.28	2,006,725.48	3.963
Beach 3-A	256,089.92	2,006,603.72	1.167
Beach 3-B	256,266.92	2,006,779.62	14.267
Beach 4-A	256,463.89	2,006,630.77	3.71
Beach 4-B	256,707.39	2,006,709.60	2.89
Beach 5-A	256,544.43	2,007,472.47	0.8
Beach 5-B	256,110.68	2,007,409.54	0.936
Beach 12-A	258,062.10	2,007,696.93	3.842
Beach 12-B	258,019.92	2,007,786.92	2.872
Beach 14-A	258,807.05	2,007,046.67	11.829
Beach 14-B	258,623.97	2,007,449.98	4.475
Beach 19-A	252,561.01	2,004,875.84	1.219
Beach 19-B	252,506.63	2,005,081.94	2.999
Beach 22-A	253,209.71	2,008,124.94	1.846
Beach 22-B	252,915.68	2,008,278.72	1.505
Beach 24-A	248,070.67	2,009,515.77	11.224
Beach 24-B	248,704.80	2,009,250.64	2.894
SWMU4-A	227,257.48	2,003,533.30	3.99
SWMU4-B	227,207.71	2,003,453.76	2.737
SWMU4-C	227,447.28	2,003,327.97	3.718
SWMU4-D	227,458.88	2,003,335.29	5.907

References

ECLS. 2012. *CH2M HILL Surveyor Report, CLEAN 8012 CTO-0013 / CLEAN 8012 CTO-0005, Location and Elevation Survey, Former Vieques Naval Training Range, Vieques, Puerto Rico*.

Attachment

The NGS Data Sheet

See file dsdata.txt for more information about the datasheet.

```
PROGRAM = datasheet95, VERSION = 8.6.1
1        National Geodetic Survey,   Retrieval Date = MARCH  6, 2015
 DN8535 ***********************************************************************
 DN8535  TIDAL BM    -  This is a Tidal Bench Mark.
 DN8535  DESIGNATION -  975 2695 A
 DN8535  PID         -  DN8535
 DN8535  STATE/COUNTY-  PR/VIEQUES
 DN8535  COUNTRY     -  US
 DN8535  USGS QUAD   -
 DN8535
 DN8535                        *CURRENT SURVEY CONTROL
 DN8535  ______________________________________________________________________
 DN8535* NAD 83(1986) POSITION- 18 05 37.87   (N) 065 28 16.89   (W)   HD_HELD1
 DN8535* PRVD02  ORTHO HEIGHT -     1.962 (meters)        6.44  (feet) ADJUSTED
 DN8535  ______________________________________________________________________
 DN8535  GEOID HEIGHT    -        -41.83  (meters)                    GEOID12A
 DN8535  VERT ORDER      -  FIRST     CLASS II
 DN8535
 DN8535.The horizontal coordinates were determined by differentially corrected
 DN8535.hand held GPS observations or other comparable positioning techniques
 DN8535.and have an estimated accuracy of +/- 3 meters.
 DN8535.
 DN8535.The orthometric height was determined by differential leveling and
 DN8535.adjusted by the NATIONAL GEODETIC SURVEY
 DN8535.in September 2013.
 DN8535
 DN8535.No vertical observational check was made to the station.
 DN8535
 DN8535.This Tidal Bench Mark is designated as VM 17949
 DN8535.by the CENTER FOR OPERATIONAL OCEANOGRAPHIC PRODUCTS AND SERVICES.
 DN8535
 DN8535.Photographs are available for this station.
 DN8535
 DN8535;                    North         East    Units  Estimated Accuracy
 DN8535;SPC PRVI     -   229,101.9     301,823.1     MT  (+/- 3 meters HH1 GPS)
 DN8535
 DN8535                          SUPERSEDED SURVEY CONTROL
```

```
DN8535
DN8535.No superseded survey control is available for this station.
DN8535
DN8535_U.S. NATIONAL GRID SPATIAL ADDRESS: 20QKF3844802321(NAD 83)
DN8535
DN8535_MARKER: DJ = TIDAL STATION DISK
DN8535_SETTING: 38 = SET IN THE ABUTMENT OR PIER OF A LARGE BRIDGE
DN8535_SP_SET: PIER
DN8535_STAMPING: 2695 A 2005
DN8535_MARK LOGO: NOS
DN8535_MAGNETIC: N = NO MAGNETIC MATERIAL
DN8535_STABILITY: C = MAY HOLD, BUT OF TYPE COMMONLY SUBJECT TO
DN8535+STABILITY: SURFACE MOTION
DN8535_SATELLITE: THE SITE LOCATION WAS REPORTED AS SUITABLE FOR
DN8535+SATELLITE: SATELLITE OBSERVATIONS - February 04, 2012
DN8535
DN8535  HISTORY     - Date     Condition        Report By
DN8535  HISTORY     - 2005     MONUMENTED       NOS
DN8535  HISTORY     - 20090901 GOOD             JAVBA
DN8535  HISTORY     - 20100302 GOOD             NOS
DN8535  HISTORY     - 20120204 GOOD             NOS
DN8535
DN8535                          STATION DESCRIPTION
DN8535
DN8535'DESCRIBED BY JAVIER E. BIDOT AND ASSOC. 2009 (JEB)
DN8535'THE TIDAL BENCH MARK IS LOCATED IN SOUTH SECTION OF VIEQUES ISLAND OFF
DN8535'THE EAST COAST OF PUERTO RICO, ABOUT 7.71KM(4.8 MI) SOUTHWEST OF SANTA
DN8535'MARIA TOWN, ABOUT 6.59KM(4.1 MI) SOUTHWEST OF VIEQUES TOWN AND IN
DN8535'ESPERANZA TOWN.
DN8535'
DN8535'TO REACH THE TIDAL BENCH MARK FROM THE INTERSECTION OF PR-996 AND
DN8535'PR-997, GO SOUTHERLY ON PR-996 FOR 0.57KM(0.4 MI) TO A SAND ROAD,
DN8535'THENCE GO ALONG THE SAND ROAD FOR 0.09KM(0.05 MI) TO A DOCK ENTRANCE,
DN8535'THENCE GO ALONG DOCK FOR 0.08KM(.04 MI) AND THE MARK TO THE FRONT.
DN8535'
DN8535'THE TIDAL BENCH MARK SET FLUSH IN A BULKHEAD OF THE PIER, 48.14M(157.9
DN8535'FT) SOUTH-SOUTHWEST OF THE DOCK ENTRANCE, NEXT TO THE NOAA TSUNAMI
DN8535'STATION, 4.55 M (14.93 FT) WEST OF THE EAST SIDE OF THE PIER, 3.80 M
DN8535'(12.47 FT) EAST OF THE WEST SIDE OF THE PIER, 3.77M(12.4 FT) NORTH OF
DN8535'A SOLAR PANEL POST, 2.97M(9.7FT) SOUTHWEST OF A WINDMILL POST, 0.91M(3
DN8535'FT) NORTH OF A MONITORING STATION, 0.51 M (1.67 FT) WEST OF THE 4 INCH
DN8535'WELL AND 0.43M(1.4 FT) WEST OF A TRANSDUCER.
DN8535'
DN8535'OWNERSHIP--MUNICIPALITY OF VIEQUES.
DN8535
DN8535                          STATION RECOVERY (2010)
```

```
DN8535
DN8535'RECOVERY NOTE BY NATIONAL OCEAN SERVICE 2010 (RJG)
DN8535'THE TIDAL BENCH MARK IS LOCATED ABOUT 7.0 KM (4.4 MI) SOUTHWEST OF
DN8535'VIEQUES TOWN, 6.3 KM (3.9 MI) SOUTHEAST OF MOSQUITO, 4.8 KM (3.0 MI)
DN8535'SOUTH-SOUTHEAST OF TJVQ AIRPORT AND IN THE TOWN OF ESPERANZA, ON THE
DN8535'ISLAND OF VIEQUES, PR.
DN8535'
DN8535'THE TIDAL BENCH MARK IS FOUND ON THE ABANDONED CONCRETE PIER ON THE
DN8535'EAST SIDE OF TOWN, NEXT TO THE NOAA TSUNAMI STATION.
DN8535'
DN8535'THE TIDAL BENCH MARK IS LOCATED 4.55 M (14.9 FT) WEST OF THE EAST SIDE
DN8535'OF THE PIER, 3.80 M (12.5 FT) EAST OF THE WEST SIDE OF THE PIER AND
DN8535'0.51 M (1.7 FT) WEST OF THE 4 INCH (10 CM) WELL, SET FLUSH IN THE
DN8535'CONCRETE PIER.
DN8535
DN8535                          STATION RECOVERY (2012)
DN8535
DN8535'RECOVERY NOTE BY NATIONAL OCEAN SERVICE 2012 (CSM)
DN8535'RECOVERED AS DESCRIBED.

*** retrieval complete.
Elapsed Time = 00:00:02
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Appendix D
Beach Surveys

APPENDIX D

Beach Surveys

This Appendix describes the beaches, locations of beach transects, equipment and personnel used, procedure, quality control and survey dates. The beach descriptions are based on observations performed during the site visit of March 2013 and the Beach Dynamics Investigation (BDI).

1. Live Impact Area Beaches, UXO 2

1.1 Beach 2 (Unnamed)

Located on the south coast of the Live Impact Area (LIA), Beach 2 (part of UXO 2) is the one of three beaches in Bahia Salina del Sur. Located on the west side of the bay, it is an approximately 20 meter (m) wide, 600 m long, sandy beach facing southeast backed by low vegetated land. It is bounded by a rocky headland to the west and a tombolo formed by a small island to the east. Beach 2 is dynamic due to its exposure to the predominant refracted waves from the southeast and storm waves from the south. However, it is not as dynamic as Beach 1 due to the wave protection offered by a reef at the east end of the bay, and an island to the southeast. This beach is often trespassed and provides nesting habitat for sea turtles. **Figure D-1** shows an aerial view of Beach 2 and a view of the beach to the southwest.

1.2 Beach 3 (Playa Salina del Sur)

Located on the south coast of the LIA, Beach 3 (part of UXO 2) is the second of three beaches in Bahia Salina del Sur. Located approximately in the center of the bay, it is an approximately 10 m wide, 150 m long, small sandy beach facing southeast, and is immediately east of Beach 2 and backed by low vegetated land. It is bounded by a tombolo formed by small island to the west and a long rocky headland to the east. Similar to Beach 2, it is protected from incoming waves by a reef to the southeast and an island to the south. Beach 3 is stable and exhibits negligible changes in a wide range of conditions. This beach is often trespassed and provides nesting habitat for sea turtles. **Figure D-2** shows an aerial view of Beach 3, and a view of the beach to the east.

1.3 Beach 4 (Turtle Beach/Playa Carrucho)

Located on the south coast of the LIA, Beach 4 (part of UXO 2) is the third of three beaches in Bahia Salina del Sur. Located on the east side of the bay and to the east of Beach 3, it is an approximately 15 m wide, 500 m long, sandy beach facing southwest and backed by low vegetated land. It is bounded by a rocky headland to the west and a sandy headland and reef to the southeast. Given its orientation and the wave protection offered by the reef and an island to the southwest, Beach 4 is stable and exhibits negligible changes in a wide range of conditions. To the northeast of the beach is Laguna Anones, whose outlet is perennially blocked by a beach berm. Only during periods of significant storms (e.g., hurricanes) has the beach berm been reportedly breached, allowing interaction between the lagoon and the bay. This beach is often trespassed and provides nesting habitat for sea turtles. **Figure D-3** shows an aerial view of Beach 4, and a view of the beach to the southeast.

1.4 Beach 5 (Icacos/Playa Yallis)

Located on the north coast of the LIA, Beach 5 (part of UXO 2) is an approximately 5 m wide, 1,100 m long, sandy and narrow beach facing north, and one of the longest beaches in the former Vieques Naval Training Range (VNTR). The beach is bounded by rocky headland to the east and a sandy headland to the west and is backed by low vegetated land. It is protected from the predominant refracted waves from the northeast by a long 1 to 2 m deep barrier reef to the north, a reef extending from the east headland, and Yallis Island to the northwest. The water body between the shore and the barrier reef, Bahia Icacos, resembles a lagoon with relatively calm water to a maximum depth of 7 m mean sea level (MSL). Beach 5 is stable and exhibits negligible changes in a wide range of conditions. This beach is often trespassed and is a nesting habitat for sea turtles. **Figure D-4** shows an aerial view of Beach 5, and a view of the beach to the east.

1.5 Beach 12 (Unnamed)

Located on the north coast of the LIA, Beach 12 (part of UXO 2) is an approximately 30 m wide, 300 m long, sandy beach facing to the northeast, and backed by approximately 5 m high vegetated dunes. It is bounded by rocky headlands on both sides and is exposed to the predominant easterly waves, and waves from the northeast during the winter. Shallow, 2 to 3 m reefs extend offshore from the headlands offering some wave protection. Beach 12 is very dynamic due to its exposure to the varying wave climate from the east and northeast. This beach is heavily used by nesting sea turtles. **Figure D-5** shows an aerial view of Beach 12, and a view of the beach to the northwest.

1.6 Beach 14 (Playa Brava)

Located on the north coast of the LIA, Beach 14 (part of UXO 2) is an approximately 40 m wide, 400 m long, sandy beach facing to the northeast, and backed by approximately 5 m high vegetated dunes. It is south of Beach 12, and similarly, Beach 14 is bounded by rocky headlands and is exposed to the predominant easterly waves, and waves from the northeast during the winter. Beach 14 is very dynamic due to its exposure to the varying wave climate from the east and northeast. This beach is heavily used by nesting sea turtles. **Figure D-6** shows an aerial view of Beach 14, and a view of the beach to the southeast.

2. North Eastern Maneuver Area and Surface Impact Area Beaches, UXO 7

2.1 Beach 22 (Puerto Diablo)

Located on the north coast of the Surface Impact Area (SIA) and Eastern Maneuver Area (EMA), Beach 22 (part of UXO 7) stretches between two bays separated by a headland. The beaches are relatively narrow, 10 to 15 m wide. The beach on the east side, also known as Puerto Diablo, is approximately 500 m long and features several rock outcrops. The beach on the west side is 300 m long. Both beaches are bounded by rocky headlands, and reefs at each side form a narrow channel where the predominant refracted waves from the northeast refract and break. Beach 22 is stable and exhibits negligible changes in a wide range of wave conditions. This beach is often trespassed and is a nesting habitat for sea turtles. **Figure D-7** shows an aerial view of Beach 22, and a view of Puerto Diablo to the east.

2.2 Beach 24 (Purple Beach/Playa Campaña)

Located on the north coast of the EMA, Beach 24 (part of UXO 7) is one of the longest beaches in the VNTR. It is an approximately 1,100 m long sandy beach facing north, with variable widths up to approximately 50 m. The beach is bounded by rocky headlands to the east and west, and it is backed by low vegetated land. It is fronted by a 2 m deep fringing reef that offers some protection to the predominant refracted waves from the northeast. Beach 24 is dynamic, in particular during the winter when deep water waves are predominant from the northeast. This beach is often trespassed and is a nesting habitat for sea turtles. **Figure D-8** shows an aerial view of Beach 24, and a view of the beach to the west.

3. South Surface Impact Area Beaches, UXO 8

3.1 Beach 1 (Yellow Beach/Playa Matías)

Located on the south coast of the SIA, Beach 1 (part of UXO 8) is an approximately 25 m wide, 1,000 m long, sandy beach facing southeast, and is one of the longest beaches in the VNTR. The beach is bounded by rocky headlands and is backed by a series of 5 m high dunes with established vegetation. Beach 1 is the most dynamic of all beaches on the south coast due to its exposure to the predominant refracted waves from the southeast, storm waves from the south, and because it is not protected by islands or reefs. The beach is a nesting habitat for sea turtles and has been identified by United States Fish and Wildlife Service (USFWS) as a potential beach for future public use. **Figure D-9** shows an aerial view of Beach 1, and a view of the beach to the west. A wide shoal is noted

on the east end of the beach, likely formed by sediment carried by the ephemeral creek that conveys rainfall collected in the watershed to the east of Cerro Matias Jalobre.

3.2 Beach 19 (Playa Yoyé)

Located on the south coast of the SIA, Beach 19 (part of UXO 8) is an approximately 5 m wide, 300 m long sandy and narrow beach facing to the southeast and backed by low vegetated land. It is exposed to refracted waves from the southeast; however, two long rocky headlands and reefs at each side form a narrow channel where waves refract and break. Beach 19 is stable and exhibits negligible changes in a wide range of wave conditions. It has been identified by the USFWS as a potential beach for future public use. **Figure D-10** shows an aerial view of Beach 19, and a view of the beach to the northeast.

4. Solid Waste Management Unit 4

Solid Waste Management Unit (SWMU) 4 is located at the west end of Vieques in the former Naval Ammunition Support Detachment (NASD), SWMU4 is two beaches separated by a shallow rocky headland, Punta Boca Quebrada. Both beaches are sandy and narrow, approximately 5 m wide, and are backed by low vegetated land. One beach faces to the southwest; it is approximately 950 m long and is bounded to the east by a rocky headland. The other is the southern 500 m stretch of the 2,000 m long beach that runs north from the southwest end of Vieques (Punta Boca Quebrada) to the northwest end (Punta Arenas). Both beaches are fronted by shallow 1 to 2 m fringing reefs and feature several rock outcrops near Punta Boca Quebrada. The wave protection offered by the shallow reefs and the orientation of the beaches relative to the predominant easterly waves make these beaches stable. However, if affected by storm waves from the west or southwest, these beaches could exhibit significant changes. Landward of the west facing beach is a mangrove lagoon (Laguna Boca Quebrada), whose outlet is perennially blocked by a beach berm. Only during periods of significant storms (e.g., hurricanes) has the beach berm been reportedly breached, allowing interaction between the lagoon and the ocean. SWMU 4 is a nesting habitat for sea turtles and has been identified by USFWS as a potential beach for future public use. **Figure D-11** shows an aerial view of SWMU 4, and a west view of the southwest-facing beach.

5. Beach Transects

For each beach, transects were arranged along the beach approximately equally spaced and perpendicular to the shoreline from a backshore boundary extending to the nearshore, covering and bracketing the beach and sea bottom areas expected to change.

Depending on the particular morphology of the beach under consideration, the backshore boundary, where the transect heads were located, was generally the toe of a bluff or cliff or the edge of vegetation. Transect heads were marked with wooden stakes driven into the ground, identified by beach and transect number, and located using a Real Time Kinetic (RTK) global positioning system (GPS) rover receiver.

To determine the offshore extent of the transects and the location of the transect toes, the depths beyond which no significant change in bottom elevation is expected in typical wave conditions were defined. This location is termed the “depth of closure” and it is typically defined through the analysis of measured profiles. However, at Vieques, these profiles were not available, and therefore a combination of empirical formulas, inspection of aerial photos, and site visit observations were used.

The formula of Hallermeier (1981) was used to estimate the depth of closure. This formula uses the nearshore wave height exceeded 12 hours each year and associated wave period. Because this information was not available, estimates of the nearshore wave conditions were made analyzing wave measurements available at St. Thomas from 2011 to 2013 and using wave transformation coefficients estimated from observations during the site visit of March 2013.

For each beach and transect, the estimated depth of closure was plotted on an aerial photo overlaid with the nearshore bathymetry, and National Oceanic and Atmospheric Administration (NOAA) BIOMapper bottom cover

and structure maps. The location of the toe of the transects was selected not to match exactly the estimated location of the depth of closure, but to contain it.

Transects at headlands were deliberately avoided, due to the fact that the underwater areas fronting them are mostly rocky, and due to the relative small and localized non-representative profile changes that may occur along them. In addition, reefs are present offshore of several headlands, for which wave breaking would have been a safety hazard for the survey crews and little to no sand is present on the reefs.

Figure D-12 through **Figure D-17** show the transect locations, bathymetry and transect head and toe coordinates for LIA UXO 2 Beaches 2, 3, 4, 5, 12, and 14; **Figure D-18** and **Figure D-19** for EMA and SIA Beaches 22 and 24; **Figure D-20** and **Figure D-21** for South SIA UXO 8 Beaches 1 and 19; and **Figure D-22** for SWMU 4.Transects were identified by beach and transect number. Starting from 1 from the right side of the beach looking seaward, transect numbers were consecutive (e.g., 1-3 = beach 1, transect 3).

6. Equipment and Personnel

Two crews surveyed the 11 beaches:

- A land crew surveyed the backshore (dry) and shoreline sections of the beach transects
- A boat crew surveyed the nearshore section of the beach transects

The following is a list of equipment and personnel used to conduct the beach surveys.

Shared by both crews:

- 1 Trimble R8 GNSS GPS base receiver to provide corrections for RTK positioning
- 1 Trimble repeater (UHF radio) to transmit the corrections to R8 GNSS Trimble rover receivers
- Trimble repeater(s) to extend the reach of the R8 GNSS GPS base receiver correction signal where necessary
- 1 unexploded ordnance (UXO) qualified personnel for performing munitions and explosives of concern (MEC) avoidance as needed with diving permit

Land crew:

- 1 R8 GNSS GPS rover receiver, including all necessary accessories, for RTK positioning
- 1 Trimble TSC3 controller
- 1 survey rod, terminated with a large flat washer to prevent the rod end from sinking in the sand
- 1 survey lead
- 1 survey assistant
- 1 UXO-qualified personnel to survey shoreline to waist depth

Boat crew:

- Zodiac Responder SRR-650 rigid-inflatable boat (RIB) equipped with 150 HP Yamaha outboard motor, anchor, fuel, batteries, compass, VHF radio, and depth sounder
- 1 Unabara HydroBook single-beam depth sounder
- 1 Unabara HydroBar speed of sound in water sensor and bar check
- 1 TRIMBLE R8 GNSS GPS rover receiver for RTK positioning
- 1 Panasonic Toughbook 31 for data acquisition/processing, including HYPACK LITE hydrographic software
- 1 Quatech QSU2-100 4-port USB to serial adapter

- 2 dedicated 12 VDC gel cell batteries, connected in parallel
- 1 DC to AC inverter
- 1 survey lead
- 1 boat driver/survey assistant
- Technical specifications of the Trimble R8 GNSS GPS receivers, Unabara HydroBook echo sounder and HydroBar speed of sound sensor, and HYPACK LITE are included as an attachment to this Appendix.

7. Procedure

The following procedure was followed for the beach surveys:

1. For each monthly survey and every day before a survey, the land and boat crews met at Camp Garcia to:
    a. Assess weather conditions and review weather forecast.
    b. Review field activities to be performed by others that day, and assess/resolve conflicts.
    c. Make a preliminary decision on the feasibility of performing the surveys that day. The decision included:
        I. Perform the surveys
        II. Postpone the surveys for later that day
        III. Cancel the surveys that day
2. If preliminary decided to perform the surveys, conducted a safety and health briefing.
3. Prepared/discussed the survey plan for the day, e.g. beach sequence and schedule.
4. Following the meeting:
    a. Land and boat crews documented summary of the meeting in their respective field notebooks.
    b. Land crew inspected and tested all GPS receivers at Camp Garcia. Documented comments in field notebook.
    c. Boat crew inspected survey boat and its equipment for obvious defects, tested software, repaired as necessary. Documented comments in field notebook.
    d. No surveys were performed if any equipment/software was not in working order.
5. Land crew set up GPS base receiver and repeater at Observation Post 1 (OP1) benchmark, set land and boat rover receivers in RTK mode, documented date/time/staff/comments in field notebook.
6. Land crew checked land and boat GPS rover receivers at the OP1 control benchmark, documented date/time/staff, and target versus acquired location/elevation in field notebook. If no centimeter (cm) level accuracy was achieved (e.g. within 3 cm horizontal/vertical), the issue was discussed/resolved.
7. Mobilized to first beach to survey, land crew by truck and boat crew by truck/trailer or water.
8. Land and boat crews assessed and made final decision on the feasibility of performing the surveys that day at that beach. Documented wind, wave, and general beach conditions at the site in their respective field notebooks. Field notebook entries included:
    a. Land crew
        i. Date/time/staff entering data
        ii. Wind speed (knots) and direction
        iii. Breaking wave height (m) and period (sec)

iv. Comments on general beach conditions

b. Boat crew

i. Date/time/staff entering data

ii. Location of observation (easting, northing, as reported by HYPACK)

iii. Water depth (m, as reported by HYPACK)

iv. Wave height (m), period (sec) and direction

v. Wind speed (knots), direction

vi. Comments on general marine conditions

9. Land crew checked land (and boat, if feasible) GPS rover receiver at a beach control benchmark. In general, more than one control benchmarks were available at each beach, but only one chosen by the crew was used. If no cm-level accuracy (e.g. 6 cm horizontal/vertical) was achieved, the crew repeated the check, and/or checked using the other benchmark. If no cm-level accuracy was still not achieved, the issue was discussed/resolved. Documented date/time/staff, target versus acquired location/elevation in field notebook.
10. Land crew delivered boat GPS rover receiver to boat crew at a convenient location. It was left to the discretion of the crews to determine if the GPS boat rover receiver had to be checked at the beach control benchmark.
11. Boat crew readied survey boat, as shown in **Figure D-23**, and launched.
12. Land crew navigated to the first transect head location, identified with a marker (wooden stake), and verified location with the land GPS rover receiver. If marker appeared to be off location, relocated.
13. Land crew set a transect marker on the shoreline (orange cone) to visualize transect heading and assist land and boat crews with alignment.
14. Land crew surveyed the backshore section of the transect by foot, then shoreline section to waist depth, as shown in **Figure D-24**. Repeated for all transects.
15. Land crew took 1 picture of each beach transect, in a direction perpendicular to the transect, centered at the top of the berm and showing the shoreline marker, as show shown **Figure D-25**. Pictures were taken from approximately the same location and in the same direction to facilitate comparison.
16. Boat crew measured, and documented in field notebook, the speed of sound in water.
17. Boat crew performed, and documented in field notebook, bar check of the single-beam depth sounder.
18. Boat crew navigated to the first transect and surveyed transect from the toe to the shore, repeated for all transects.
19. Land and boat crews documented in their respective field notebooks any surveying issues (e.g. data quality, operational, equipment/software, etc.)
20. Land and boat crews travelled to the next beach and surveyed following the steps listed above.
21. Upon completion of the surveys planned for the day, land crew removed GPS base receiver and repeater from OP1, and crews returned to Camp Garcia.
22. Crews secured equipment for overnight storage and placed all rechargeable batteries on charge.

8. Quality Control

This section details the quality control analyses performed on the data collected and observations made in the field.

8.1 Field Notebooks

Information recorded on field notebooks was “spot-checked” to verify and fix data entered in the summary spreadsheets.

8.2 Survey Dates and Staff

Information recorded in field notebooks regarding what beaches were surveyed, when, and list of staff performing the surveys were reviewed. Dates were checked against time-stamped files to ensure date and time consistency.

8.3 Control Benchmark Checks

Figure D-26, **Figure D-27** and **Figure D-28** show the history of land GPS rover receiver control benchmark checks throughout the BDI in terms of the discrepancies (acquired – target) for easting, northing, and elevation, respectively. The same magnitude of discrepancies should be expected for the boat GPS rover receiver, which was checked occasionally. **Table D-1** presents statistics of these checks in terms of mean and maximum absolute discrepancy; OP1 CONTROL includes boat GPS rover receiver checks. Discrepancies in horizontal position and elevation are well within the accuracy needed for beach surveys; therefore, the survey data were accurate for the purposes of the BDI.

Table D-1. Statistics of control benchmark checks, discrepancy = acquired – target, OP1 CONTROL includes boat GPS rover receiver.

		Discrepancy (m)					
		Easting		Northing		Elevation	
Benchmark	**Count**	**Mean**	**Max**	**Mean**	**Max**	**Mean**	**Max**
OP1 CONTROL	205	0.00	0.06	0.00	0.03	-0.01	0.05
Mt. Pirata CONTROL	24	0.00	0.01	0.02	0.04	-0.01	0.03
Beach 1-A	3	-0.10	0.12	0.06	0.06	0.01	0.02
Beach 1-B	20	-0.05	0.08	0.07	0.09	0.00	0.01
Beach 2-A	22	-0.01	0.06	0.02	0.04	-0.01	0.04
Beach 3-A	13	0.01	0.04	0.01	0.02	0.00	0.04
Beach 3-B	1	0.00	0.00	0.00	0.00	0.00	0.00
Beach 4-A	3	-0.10	0.11	-0.06	0.06	0.02	0.04
Beach 4-B	11	0.09	0.11	0.00	0.02	-0.02	0.04
Beach 5-A	13	0.02	0.05	0.01	0.03	0.00	0.03
Beach 5-B	1	0.00	0.00	0.02	0.02	0.00	0.00
Beach 12-A	19	-0.08	0.10	0.00	0.01	0.05	0.12
Beach 12-B	2	-0.09	0.09	0.00	0.01	0.03	0.03
Beach 14-A	2	0.05	0.07	0.02	0.04	0.07	0.12
Beach 14-B	20	-0.04	0.06	-0.04	0.06	0.03	0.07
Beach 19-A	1	-0.02	0.02	-0.01	0.01	0.02	0.02

Table D-1. Statistics of control benchmark checks, discrepancy = acquired – target, OP1 CONTROL includes boat GPS rover receiver.

		Discrepancy (m)					
		Easting		Northing		Elevation	
Benchmark	**Count**	**Mean**	**Max**	**Mean**	**Max**	**Mean**	**Max**
Beach 19-B	13	-0.01	0.03	0.00	0.01	0.00	0.02
Beach 22-A	13	0.01	0.03	0.01	0.04	0.00	0.09
Beach 22-B	2	0.00	0.01	-0.01	0.01	0.00	0.01
Beach 24-A	20	-0.06	0.10	-0.03	0.06	0.01	0.07
Beach 24-B	2	0.01	0.01	0.05	0.05	0.00	0.00
SWMU4-A	1	-0.01	0.01	-0.05	0.05	-0.07	0.07
SWMU4-B	2	0.02	0.02	-0.04	0.04	-0.05	0.08
SWMU4-C	12	0.01	0.02	0.01	0.03	-0.02	0.07
SWMU4-D	2	0.01	0.02	-0.01	0.03	-0.05	0.06

9. Survey Dates

A total of 21 beach surveys (approximately 1 per month) were performed between April 2015 to December 2016. For any given beach, land and nearshore surveys were generally performed on the same day, but in some cases took place over 2 to 3 days due to weather conditions or other logistics issues. Because beach profiles can change relatively quickly, no land and nearshore surveys were performed more than 2 days apart on any beach. **Table D-2** lists the dates of the surveys for each beach.

Table D-2. Beach survey dates.

Survey	Beach										
	1	**2**	**3**	**4**	**5**	**12**	**14**	**19**	**22**	**24**	**S4**
2015											
1	4/6	4/2-4	4/4	4/4	4/1	4/1	3/31	4/6	4/3	4/7-8	
2	5/14-15	5/4	5/4	5/4-5	5/5	4/28-29	4/28-29	5/7	5/5-6	4/30	5/8
3	6/10-11	6/9-10	6/9-10	6/9	6/11	6/16	6/16	6/11	6/15	6/15	6/12
4	7/16	7/13-14	7/13-14	7/14	7/7	7/17	7/17	7/14	7/16	7/16-17	7/15
5	8/12	8/13	8/13	8/12	8/11-12	8/13	8/13	8/12	8/11	8/11	8/14
6	9/17	9/16	9/16	9/16	9/14-15	9/17-18	9/17-18	9/16-17	9/15	9/15	9/21
7	10/16	10/13	10/13	10/13	10/14	10/19	10/19	10/13-14	10/14	10/15	10/21
8	11/10	11/17	11/17	11/11	11/13	11/12	11/12-13	11/17	11/10	11/18	11/16
9	12/16	12/14	12/14	12/14	12/11	12/11	12/10-11	12/10	12/9	12/9	12/15

Table D-2. Beach survey dates.

Survey	Beach										
	1	**2**	**3**	**4**	**5**	**12**	**14**	**19**	**22**	**24**	**S4**
2016											
10	1/11	1/6	1/6	1/6	1/8	1/15	1/15	1/12	1/5	1/13	1/7
11	2/12	2/9	2/9	2/9	2/11	2/19	2/19	2/10	2/17	2/18	2/15
12	3/8	3/9	3/9	3/9	3/7	3/15-16	3/15-16	3/8	3/7	3/12*	3/10
13	4/13	4/8	4/8	4/8	4/4	4/6	4/6	4/7	4/4	4/6	4/11
14	5/5	5/5				5/4	5/4			5/3	
15	6/9	6/7				6/8	6/8			6/16	
16	7/15	7/15				7/18	7/18			7/16	
17	8/9	8/8				8/10	8/10			8/12	
18	9/7	9/7				9/10	9/10			9/8-9	
19	10/6	10/3-4								10/4-5	
20	11/8	11/8				11/11	11/11			11/7	
21	12/6	12/6				12/7	12/7			12/8-9	

* land survey only
shaded survey-beach indicate survey not performed
S4 = SWMU 4

10. References

BIOMapper. Vieques, Puerto Rico. http://maps.coastalscience.noaa.gov/biomapper/biomapper.html?id=Vieques. Accessed July 2016.

Hallermeier, R.J. 1981. "A profile zonation for seasonal sand beaches from wave climate." *Coastal Engineering.* Vol. 4, pp. 253-277.

Attachment

Trimble R8s GNSS SYSTEM

PERFORMANCE SPECIFICATIONS[1]

Measurements

- Advanced Trimble Maxwell 6 Custom Survey GNSS chips with 440 channels
- Future-proof your investment with Trimble 360 tracking
- High precision multiple correlator for GNSS pseudorange measurements
- Unfiltered, un-smoothed pseudorange measurements data for low noise, low multipath error, low time domain correlation and high dynamic response
- Very low noise GNSS carrier phase measurements with <1 mm precision in a 1 Hz bandwidth
- Signal-to-Noise ratios reported in dB-Hz
- Proven Trimble low elevation tracking technology
- Satellite signals tracked simultaneously:
  - GPS: L1C/A, L1C, L2C, L2E, L5
  - GLONASS: L1C/A, L1P, L2C/A, L2P, L3
  - SBAS: L1C/A, L5 (for SBAS satellites that support L5)
  - Galileo: E1, E5A, E5B
  - BeiDou (COMPASS): B1, B2
- SBAS: QZSS, WAAS, EGNOS, GAGAN
- Positioning rates: 1 Hz, 2 Hz, 5 Hz, 10 Hz, and 20 Hz

POSITIONING PERFORMANCE[2]

Code differential GNSS positioning

Horizontal . . . . . 0.25 m + 1 ppm RMS
Vertical . . . . . 0.50 m + 1 ppm RMS
SBAS differential positioning accuracy[3] . . . . . typically <5 m 3DRMS

Static GNSS surveying

High-Precision Static
Horizontal . . . . . 3 mm + 0.1 ppm RMS
Vertical . . . . . 3.5 mm + 0.4 ppm RMS
Static and Fast Static
Horizontal . . . . . 3 mm + 0.5 ppm RMS
Vertical . . . . . 5 mm + 0.5 ppm RMS

Postprocessed Kinematic (PPK) GNSS surveying

Horizontal . . . . . 8 mm + 1 ppm RMS
Vertical . . . . . 15 mm + 1 ppm RMS

Real Time Kinematic surveying

Single Baseline <30 km
Horizontal . . . . . 8 mm + 1 ppm RMS
Vertical . . . . . 15 mm + 1 ppm RMS
Network RTK[4]
Horizontal . . . . . 8 mm + 0.5 ppm RMS
Vertical . . . . . 15 mm + 0.5 ppm RMS
Initialization time[5] . . . . . typically <8 seconds
Initialization reliability[5] . . . . . typically >99.9%

HARDWARE

Physical

Dimensions . . . . . 19 cm x 10.4 cm (7.5 in x 4.1 in), including connectors
Weight . . . . . 1.52 kg (3.35 lb) with internal battery, internal radio and antenna
3.81 kg (8.40 lb) items above plus range pole, controller & internal radio
Operating Temperature[6] . . . . . –40 °C to +65 °C (–40 °F to +149 °F)
Storage Temperature . . . . . –40 °C to +75 °C (–40 °F to +167°F)
Humidity . . . . . 100%, condensing
Ingress Protection . . . . . IP67 dustproof, protected from temporary immersion to depth of 1 m (3.28 ft)
Shock and vibration . . . . . Tested and meets the following environmental standards:
Shock . . . . . Non-operating: Designed to survive a 2 m (6.6 ft) pole drop onto concrete. Operating: to 40 G, 10 msec, sawtooth
Vibration MIL-STD-810F, FIG.514.5C-1

ELECTRICAL

- Power 10.5 V DC to 28 V DC external power input with over-voltage protection on Port 1 (7-pin Lemo)
- Rechargeable, removable 7.4 V, 2.8 Ah Lithium-ion smart battery
- Power consumption is <3.2 W in RTK rover mode with internal radio and Bluetooth® in use[7]
- Operating times on internal battery[8]:
  - 450 MHz receive only option. . . . . 5.0 hours
  - 450 MHz receive/transmit option (0.5 W) . . . . . 2.5 hours
  - Cellular receive option. . . . . 4.0 hours

COMMUNICATIONS AND DATA STORAGE

- Serial: 3-wire serial (7-pin Lemo) on Port 1; full RS-232 serial (Dsub 9 pin) on Port 2
- Radio Modem[1]: fully Integrated, sealed 450 MHz wide band receiver/transmitter with frequency range of 403 MHz to 473 MHz, support of Trimble, Pacific Crest, and SATEL radio protocols:
  - Transmit power: 0.5 W
  - Range: 3–5 km typical / 10 km optimal[9]
- Cellular[1]: fully integrated, sealed internal GSM/GPRS/EDGE/UMTS/HSPA+ modem option. CSD (Circuit-Switched Data) and PSD (Packet-Switched Data) supported. Global Operation:
  - Penta-Band UMTS/HSPA+ (850/800, 900, 1900, and 2100 MHz)
  - Quad-Band GSM/CSD & GPRS/EDGE (850, 900, 1800, and 1900 MHz)
- Bluetooth: fully integrated, fully sealed 2.4 GHz communications port (Bluetooth)[10]
- External communication devices for corrections supported on Serial and Bluetooth ports
- Data storage: 56 MB internal memory, 960 hours of raw observables (approx. 1.4 MB/day), based on recording every 15 sec from an average of 14 satellites

Data Formats

- CMR, CMR+, CMRx, RTCM 2.1, RTCM 2.3, RTCM 3.0, RTCM 3.1, RTCM 3.2 inputs and outputs
- 23 NMEA outputs, GSOF, RT17 and RT27 outputs, supports BINEX and smoothed carrier

WebUI

- Offers simple configuration, operation, status, and data transfer
- Accessible via Serial and Bluetooth

Supported Trimble Controllers[1]

- Trimble TSC3, Trimble Slate, Trimble CU, Trimble Tablet Rugged PC

CERTIFICATIONS

IEC 60950-1 (Electrical Safety); FCC OET Bulletin 65 (RF Exposure Safety); FCC Part 15.105 (Class B), Part 15.247, Part 90; PTCRB (AT&T); Bluetooth SIG; IC ES-003 (Class B); Radio Equipment Directive 2014/53/EU, RoHS, WEEE; Australia & New Zealand RCM; Japan Radio and Telecom MIC

1 Based on Trimble R8s GNSS receiver configuration. Radio frequency settings are country specific.
2 Precision and reliability may be subject to anomalies due to multipath, obstructions, satellite geometry, and atmospheric conditions. The specifications stated recommend the use of stable mounts in an open sky view, EMI and multipath clean environment, optimal GNSS constellation configurations, along with the use of survey practices that are generally accepted for performing the highest-order surveys for the applicable application including occupation time appropriate for baseline length. Baselines longer than 30 km require precise ephemeris and occupations up to 24 hours may be required to achieve the high precision static specification.
3 Depends on SBAS system performance.
4 Network RTK PPM values are referenced to the closest physical reference station.
5 May be affected by atmospheric conditions, signal multipath, obstructions and satellite geometry. Initialization reliability is continuously monitored to ensure highest quality.
6 Receiver will operate normally to –40 °C, internal batteries are rated to –20 °C, optional internal cellular modem operates to –40 °C.
7 Tracking GPS, GLONASS and SBAS satellites.
8 Varies with temperature and wireless data rate. When using a receiver and internal radio in the transmit mode, it is recommended that an external 6 Ah or higher battery is used. The specified operating times on an internal battery for the cellular receive option are in GSM CSD (Circuit-Switched Data) or GPRS PSD (Packet-Switched Data) mode.
9 Varies with terrain and operating conditions.
10 Bluetooth type approvals are country specific.

Specifications subject to change without notice.

Contact your local Trimble Authorized Distribution Partner for more information

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HydroBook™

Hydrographic Echo Sounder

Specification Overview

Depth Range: 0.1 meter to 200 meters
0.3 feet to 660 feet

Depth Resolution: 0.001 meter (1 millimeter) 25 meter range
0.01 (1 centimeter) above 25 meter range
0.1 foot

Minimum Depth: 0.1 meters (below bottom face of BSU)
0.3 feet

Frequency Agility: 180 Khz. thru 280 Khz.

Acoustic Beamwidth: 10 degrees thru 5.0 degrees
(see Figure 1 – Beamwidth/Ensonification @ 10 meters depth)

Ping (sounding rate): User-selectable 5 thru 30 hertz.

TVG: 10 Log, 20 Log or 30 Log (auto selected based upon depth)

User Inputs (via PC APP):

- Range & Units (feet or meters)
- Frequency/Beamwidth
- Offset (Draft + Index)
- Sound Velocity
- Gate
- Output Type & Baud Rate
- Ping (sounding) Rate
- On/Off

COM PORTS: COM 1 – Dedicated to HydroBook APP Sofware
COM 2 – Depth Output to PC (for Hypack or other)

COM 2 Baud Rate: 9600, 19200, 38400, 57600 or 115200; 8N1
(SEE APPENDIX A FOR DATA OUTPUTS)

Power Input: 12 volts D.C. (11 to 16 vdc nominal) @ 125 ma.

Beamwidth/Ensonification

The below figure serves to give the user a perspective of sonar beam diameter (Cell Footprint) at various beamwidths, at an example depth of 10 meters. For planning and reference during surveys, the HydroBook provides a real-time display of the diameter of the ensonified footprint at the current depth of survey.

Figure 1

Below the various acoustic frequencies and corresponding beamwidths of the HydroBook are presented along with the beamwidth diameter in meters (rounded) of the respective ensonified footprint @ 10 meters.

Frequency (kHz)	*Wave Length (mm)*	*Beamwidth (deg)*	*Cell Footprint Diameter (Meters)*
180	8.33	10.0	1.7
190	7.89	9.5	1.6
200	7.50	9.0	1.6
210	7.14	8.5	1.5
220	6.82	8.0	1.4
230	6.52	7.5	1.3
240	6.25	7.0	1.2
250	6.00	6.5	1.1
260	5.77	6.0	1.0
270	5.56	5.5	1.0
280	5.36	5.0	0.9

HydroBook Hardware Deliverables

Each HydroBook system includes: - HydroBook Below Surface Unit (with 10 meter Cable & Weatherproof Plug) - BSU Adaptor Cable (BSU to COM 1/COM 2/Power Input) - USB-Memory Pod - User's Manual (English Edition) - 2 ea. RS-232 to USB Adaptors (for PC's without Serial Ports)

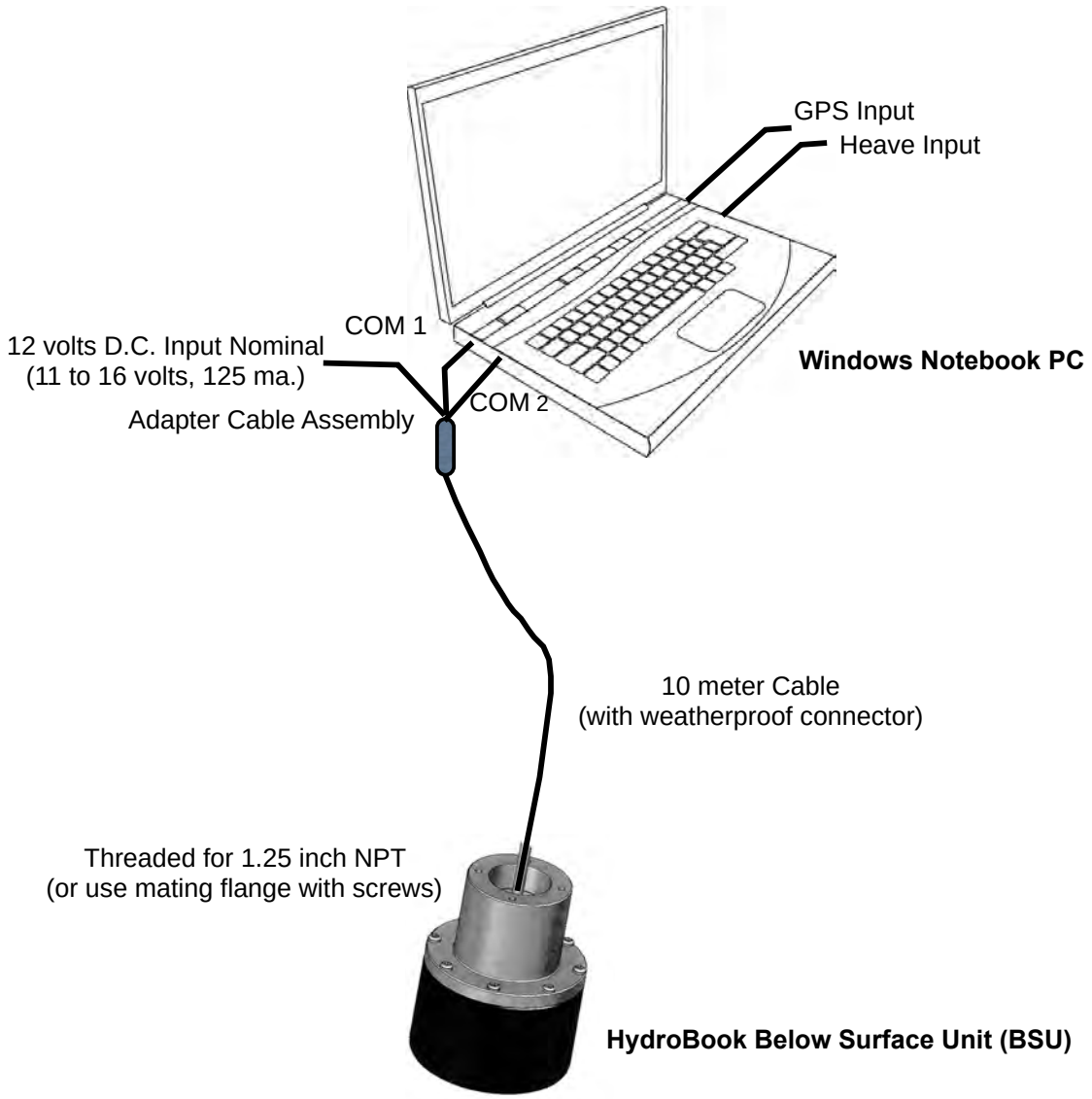


Figure 2

TM

HydroBar

Poduct Overview

The major deliverable of your HydroBar system is the underwater unit shown in Figure 1. This unit contains the precision sound velocimeter, pressure (depth) sensor, temperature sensor and internal electronics. Data is sent to the surface via a depth marked, Kevlar reinforced, tether cable. Markings are available either in metric or english units. The standard length tether cable is 20 meters (66 feet); optional longer lengths are available. Integral to this unit is the sonar target ("bar") which has a surface texture designed to provide enhanced acoustic reflectivity. Below the target is an integral cable reel (patent pending) to allow convenient storage of the tether cable.

At the surface end of the tether cable is a weatherproof connector with protective storage cover. This connector mates with an adapter cable which plugs into any available USB port on your Windows computer. A stainless steel strain relief loop is provided at the weatherproof connector to secure the surface end.

The HydroBar's Windowsp based software APP with drivers for the adapter cable along with this HydroBar Operation Manual are contained on a USBp Memory Pod supplied with each HydroBar system.

When using the BAR CHECK mode, the HydroBar PC program will use the readings from the user's echo sounder to calculate errors. The echo sounder depth reading at a particular bar depth will be entered by the user via the PC keyboard; alternately, the user may use serial depth data from the echo sounder so that depth is provided to the HydroBar APP without the need for the user to enter depth via the keyboard. (See Appendix A for information on automatic depth input).

There is no power cable, power supply or battery pack included in the HydroBar deliverables as none is required; power for the HydroBar is supplied by the user's PC via the USB port.

Specification Overview

Parameters:

Sound Velocity Range: 1375 to 1700 meters/second
(4538 to 5610 feet/second)

Resolution (as displayed on APP): 0.1 meters/second
(0.1 feet/second)

Temperature Range: - 5 deg. C to 40 deg. C
(23 deg. F to 104 deg. F)

Resolution (as displayed on APP): 0.01 deg. C
(0.01 deg. F)

Depth Range: (defined by tether cable length)
(20 meters/ 66 feet STANDARD; other lengths optional)

Resolution (as displayed on APP): 0.1 meters
(1 foot)

Depth Measurement Note: Although the HydroBar has an integral pressure sensor for determining the HydroBar's depth during the CAST, this sensor is not used during the Bar Check Mode; when performing bar checks, the depth of the target needs to be known with millimeter certainty. The tether cable is of "no stretch" design and has a Kevlar jacket for extreme durability. This cable is precisely marked to insure accuracy when performing a bar check.

Cable Note: Specify English or Metric markings on tether cable for Bar Check when ordering.

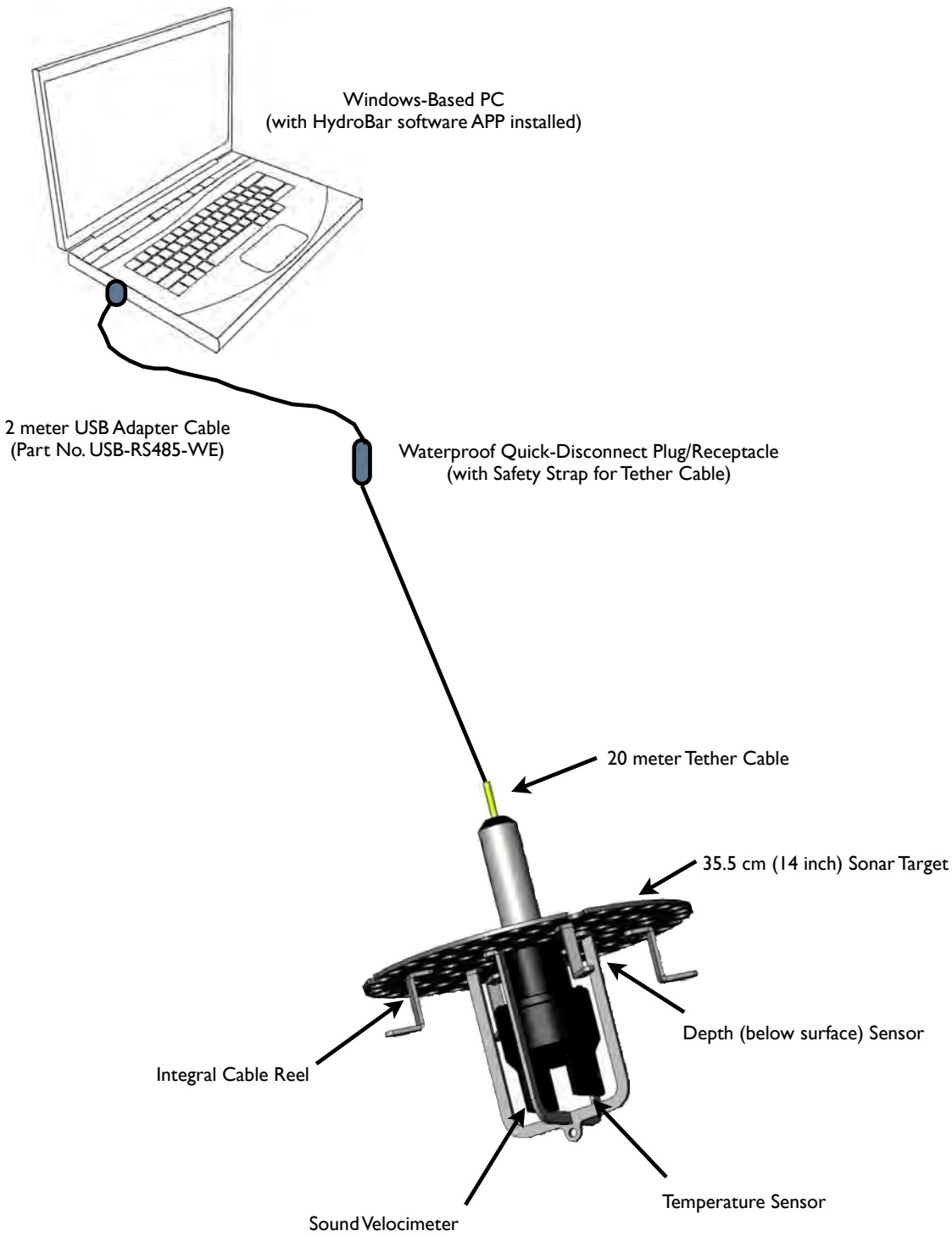

Windows-Based PC
(with HydroBar software APP installed)
2 meter USB Adapter Cable
(Part No. USB-RS485-WE)
Waterproof Quick-Disconnect Plug/Receptacle
(with Safety Strap for Tether Cable)
20 meter Tether Cable
35.5 cm (14 inch) Sonar Target
Depth (below surface) Sensor
Integral Cable Reel
Temperature Sensor
Sound Velocimeter

Figure 1

HYPACK LITE

General	
Product Name:	HYPACK LITE
Product Description:	HYPACK® LITE: Single beam package designed for users who will perform their final product work in a CAD-GIS package. It contains all of the programs necessary to design your survey and collect single beam data, process and export it to DXF/DGN for import into your CAD GIS package.
Year of initial development:	1995
Year of latest version:	2017
Operating System:	Windows 2007/8/10
Area of Application:	Hydrographic Surveying, Navigation. Data collection of Single beam and ancillary sensors
Hardware Requirements	
RAM:	4
HD (GB):	250
Processor (CPU):	32, 64 bit
Languages supported:	English, Spanish, French, Russian and dozens more
Geodetic Functionality	
Supported coordinate systems:	Over 100 supported, WGS84, NAD27
Supported datum transformations:	Geoid models, user defined
Geographical coordinates (Lat, Long):	YES
Ground coordinates (E,N):	YES
Seven parameter shift supported:	YES
Time-dependent Transformation	YES

Geodetic Functionality	
Parameters (14param):	
Supported vertical reference frames:	YES
Separation model for vertical datum shift support:	YES
Local datum support:	YES
Ellipsoidal reference support (GRS80):	YES
Supported map projections:	YES
Data / System Support	
Recorded data storage formats:	RAW (HYPACK format)
Supported hydrographic Systems:	Single Beam and All ancillary sensors for survey work, including GPS, SV, Heading, Motion.
Supported AUVs:	NO
Supported ROVs:	NO
Supported ROTVs:	NO
Supported underwater positioning systems:	NO
Supported multibeam systems:	NO
Supported surface positioning systems:	GPS, USBL, INS
Supported singlebeam systems:	Yes, Odom, Ceeducer, Knudsen, Atlas, Kongsberg, Navisound, Reson, Ross
Supported sidescan sonar systems:	NO
Supported magnetometer systems:	Geomatics, Marine Magnetics, JWFisher, Quantro Sensing, Scintrex Envigrad
Supported gyrocompass systems:	All NMEA format output sensors are support, Applanix, KVH, TSS, Novatel,

Data / System Support	
Supported motion sensor systems:	All TSS1 format output sensors are supported, Applanix, SBG, TSS, IXSEA, Kongsberg
Supported imaging systems:	NO
Supported sub-bottom Profiler systems:	All analog sonars, Edgetech, Innomar, Knudsen, Specialty Devices, SyQuest,
Supported total station systems:	Leica, Trimble
Supported ADCP systems:	Sontek, RDI, Nortek
Supported (underwater) laser scanner systems:	NO
Supported INS:	Applanix, SBG, Novetel
Metadata management:	YES
Time synchronization methods:	Veritime (HYPACK proprietary), PPS, ZDA, GGA
Online Capabilities	
Helmsman display:	YES
Max. number cloned displays:	4
Supported background formats:	BSB, S57, S63, DXF, DGN, DWG, ECW, MIF, JPEG2000, PDF files, PNG, Mr SID, TIF
Available real-time cleaning techniques:	NO
Type of navigation screens:	Multiple displays, independent. Display with lines (heads up, north up, vessel up)
Survey data types real-time navigation display:	Trackline, sounding, matrix (color filled grid)
Max number of online displayed ROVs:	16
Max number of online displayed surface vessels:	16

Online Capabilities	
Computed orientation solution:	NO
3D real time display:	NO
Supported 3D display data :	YES
Real time tidal correction methods:	RTK
RTK GPS height correction:	YES
Real time video integration:	NO
Real-time Pipe detection:	NO
Real time IHO / IMCA TPU support:	YES
SSS waterfall display:	NO
SSS target annotations:	NO
Backscatter display:	NO
Online filtering options:	MIN and MAX depth (display only, all data is logged)
Status Views equipment:	Quality control view for data sensor input, thresholds
Multibeam bathymetry coverage:	NO
Multibeam water column display:	NO
GIS integration:	
Remote control:	NO
Real-time DTM vizualization:	NO
Online eventing:	YES
Real-time DTM comparison:	NO

Figures

Aerial source 2017 Google Earth. Image U.S. Geological Survey.

FIGURE D-1
Aerial View of Beach 2 (top) and a View of the Beach to the Southwest (bottom)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2017 Google Earth. Image U.S. Geological Survey.

FIGURE D-2
Aerial View of Beach 3 (top) and a View of the Beach to the East (bottom)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2017 Google Earth. Image U.S. Geological Survey.

FIGURE D-3
Aerial View of Beach 4 (top) and View to the Southeast (bottom)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2017 Google Earth. Image U.S. Geological Survey.

FIGURE D-4
Aerial View of Beach 5 (top) and a View of the Beach to the East (bottom)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2017 Google Earth. Image U.S. Geological Survey.

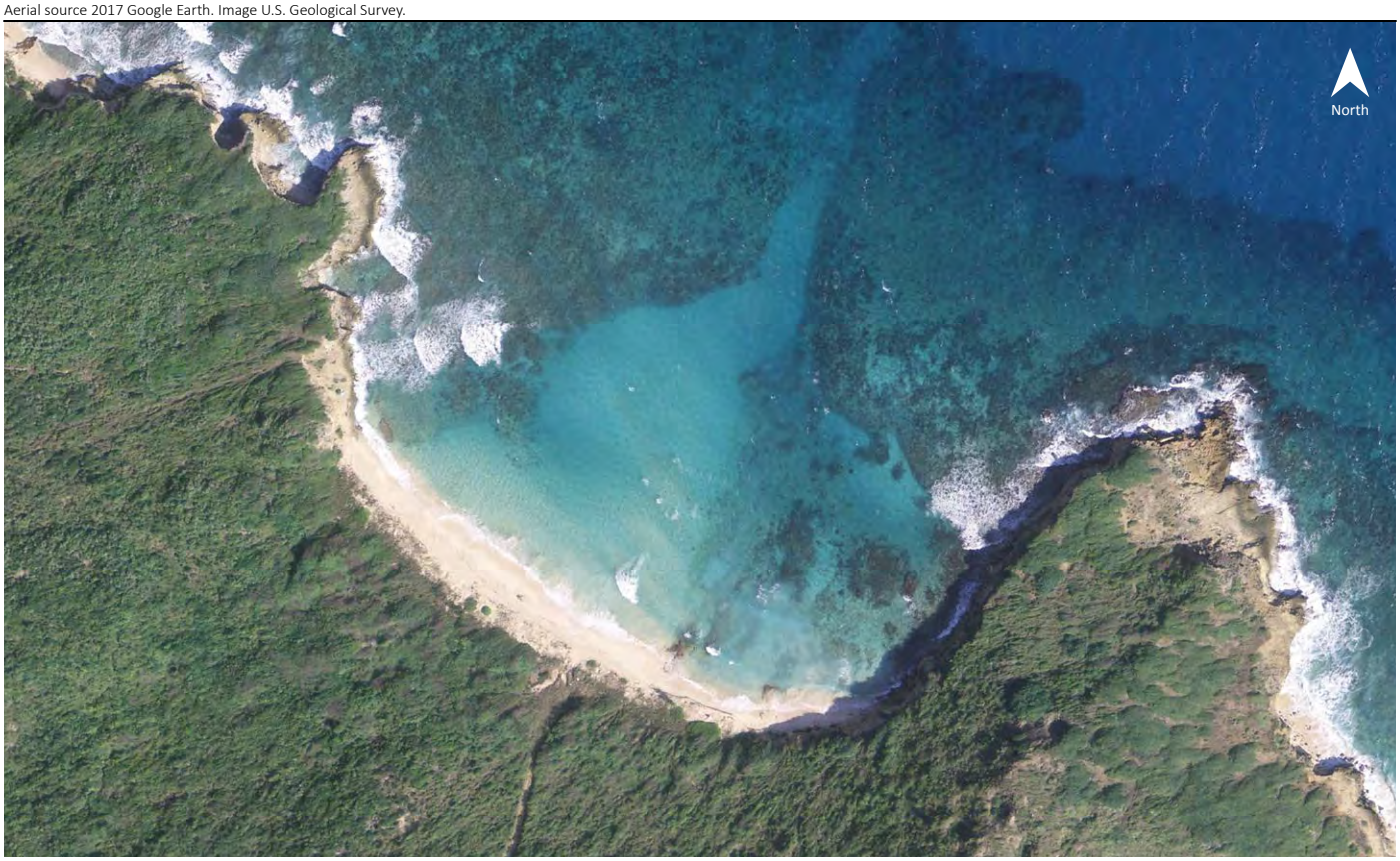


FIGURE D-5
Aerial View of Beach 12 (top) and a View of the Beach to the Northwest (bottom)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2017 Google Earth. Image U.S. Geological Survey.

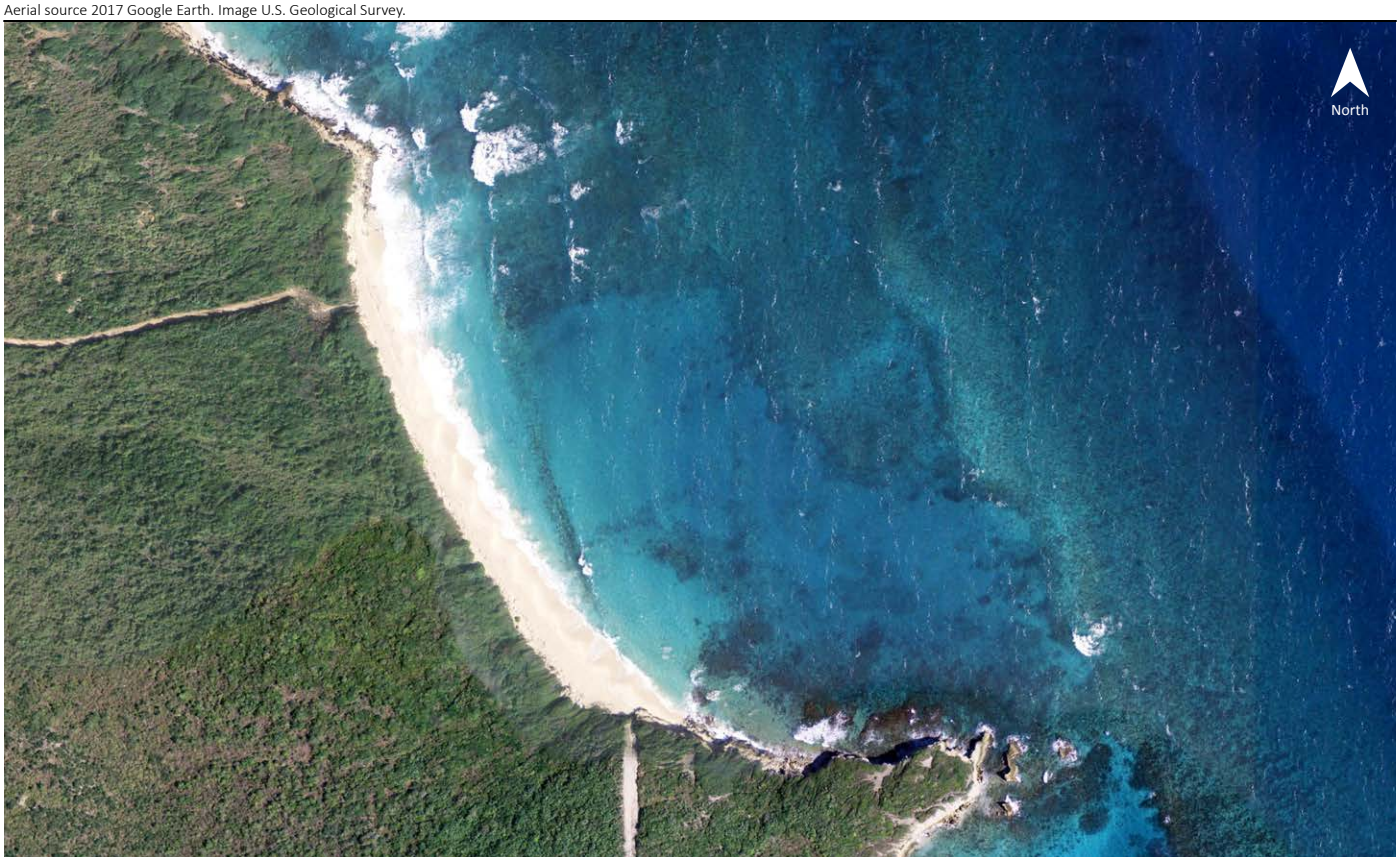


FIGURE D-6
Aerial View of Beach 14 (top) and a View of the Beach to the Southeast (bottom)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2017 Google Earth. Image U.S. Geological Survey.

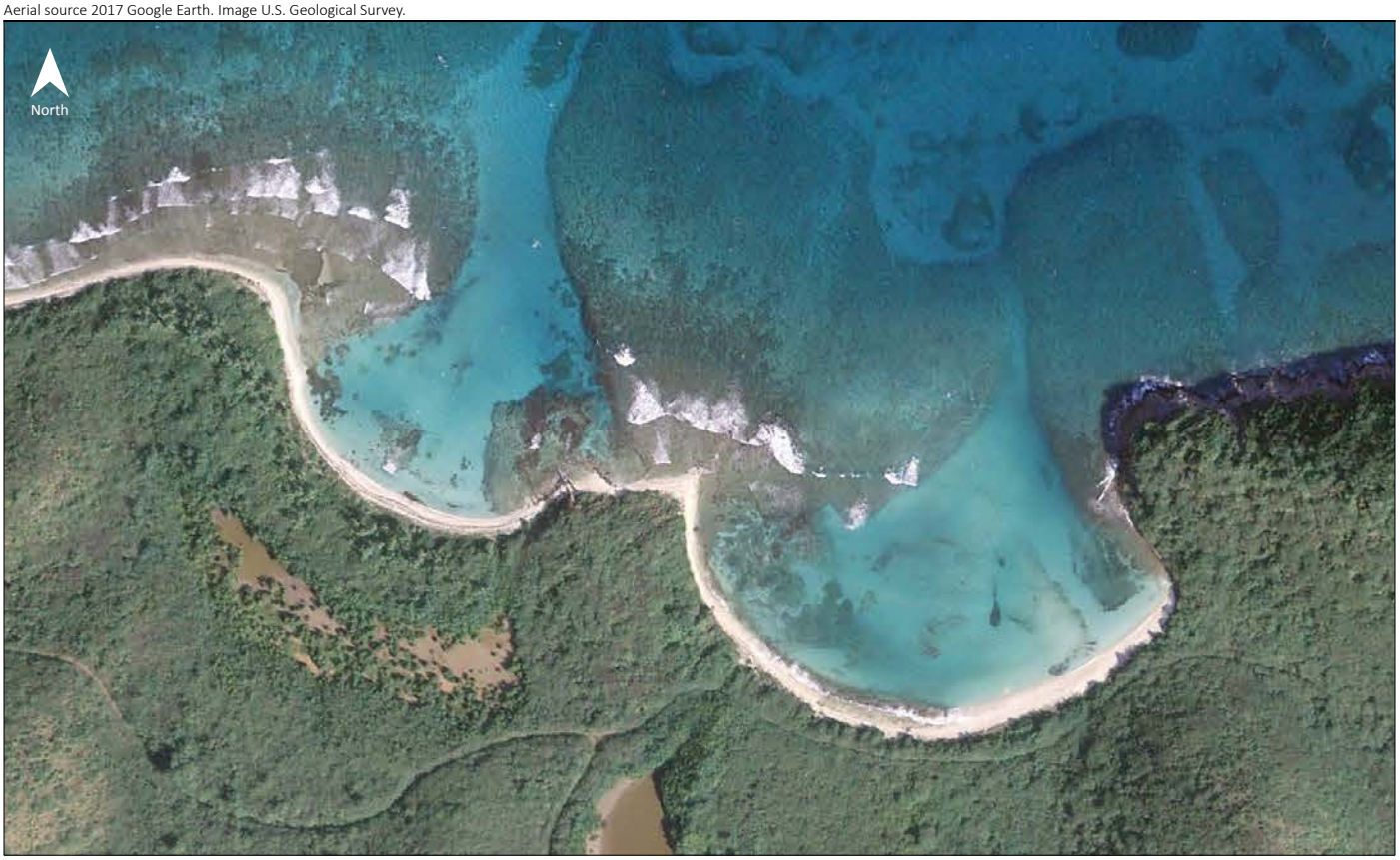


FIGURE D-7
Aerial View of Beach 22 (top) and View of Puerto Diablo to the East (bottom)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2017 Google Earth. Image U.S. Geological Survey.

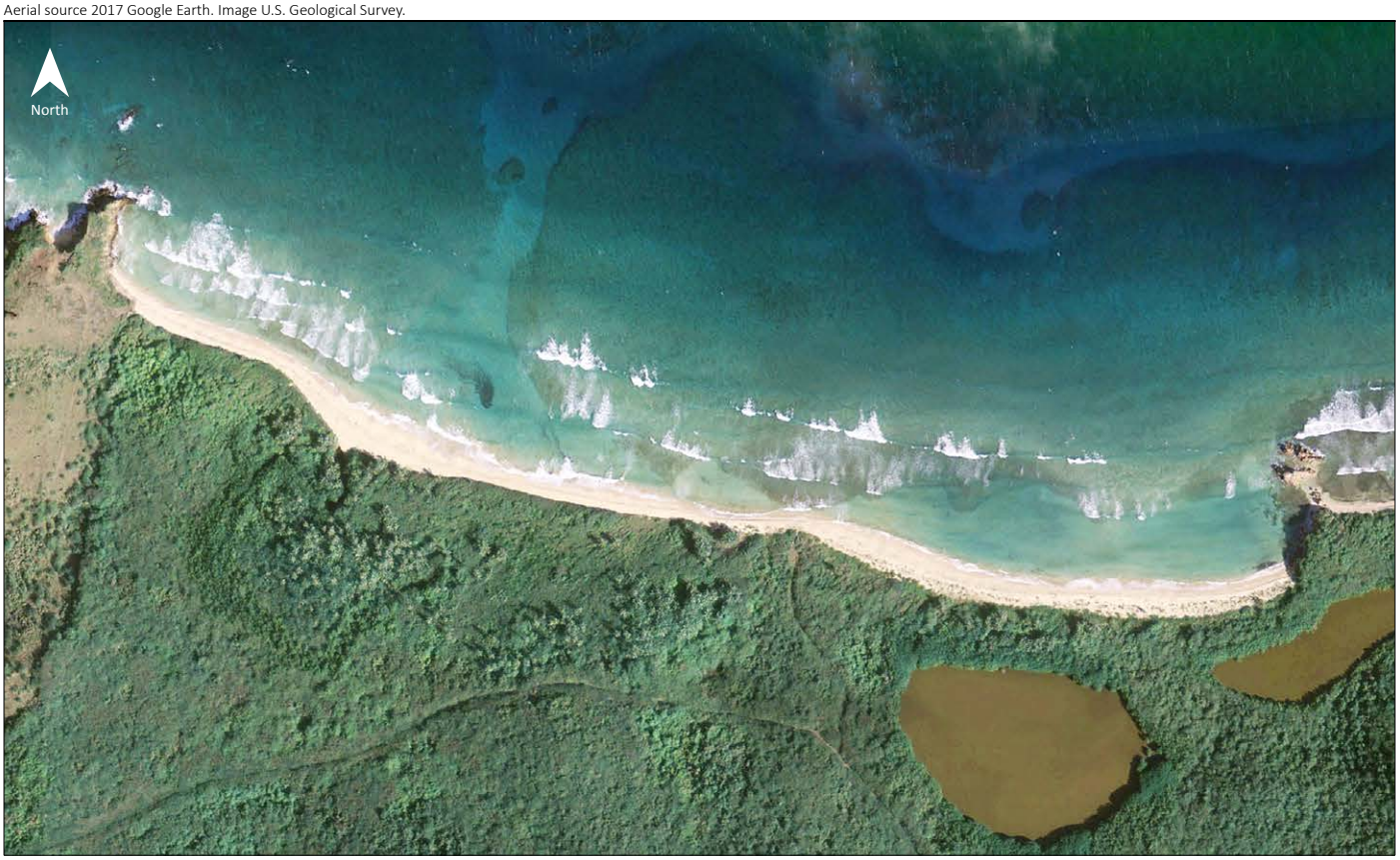


FIGURE D-8
Aerial View of Beach 24 (top) and a View of the Beach to the West (bottom)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2017 Google Earth. Image U.S. Geological Survey.

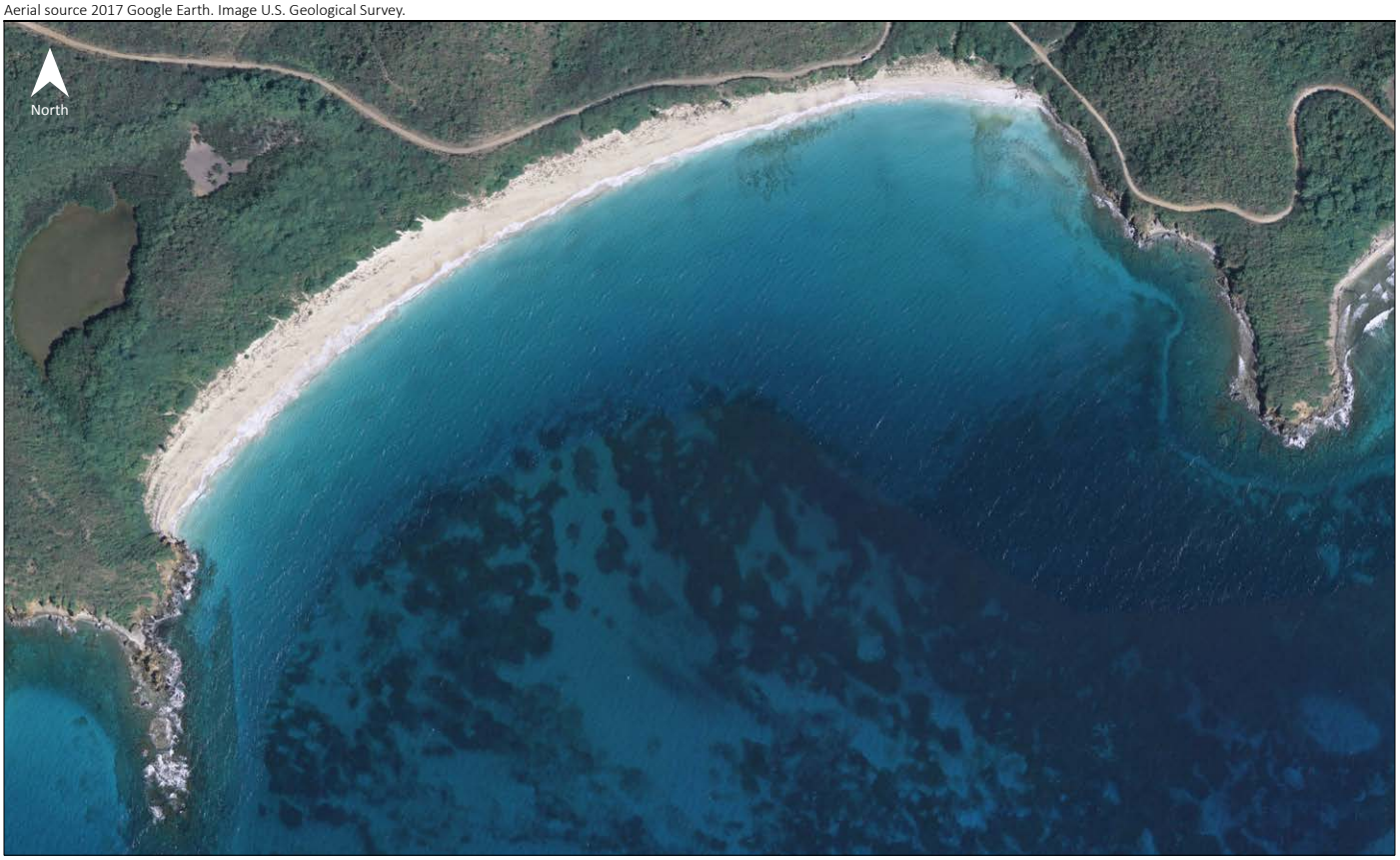


FIGURE D-9
Aerial View of Beach 1 (top) and a View of the Beach to the West (bottom)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2017 Google Earth. Image U.S. Geological Survey.

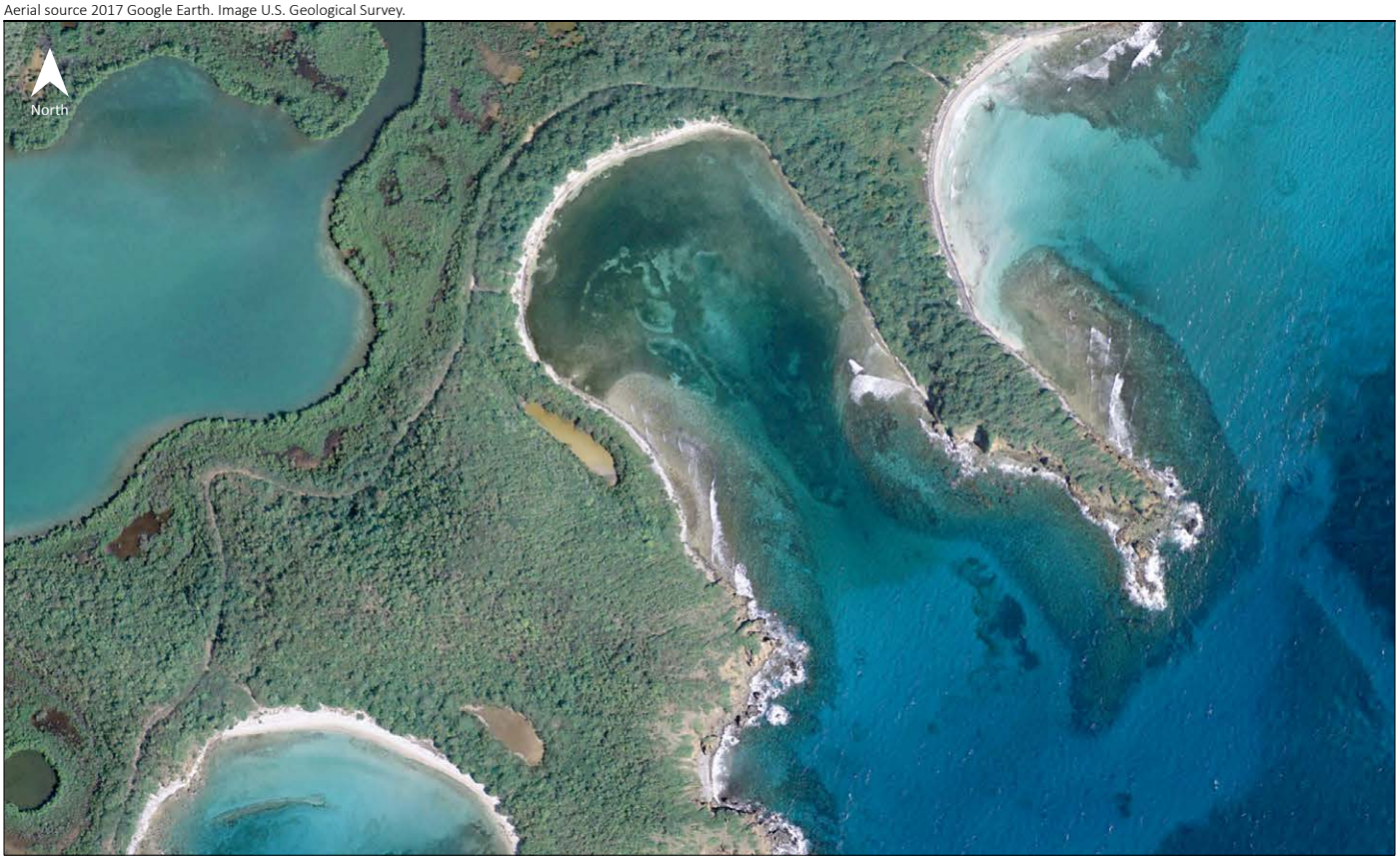
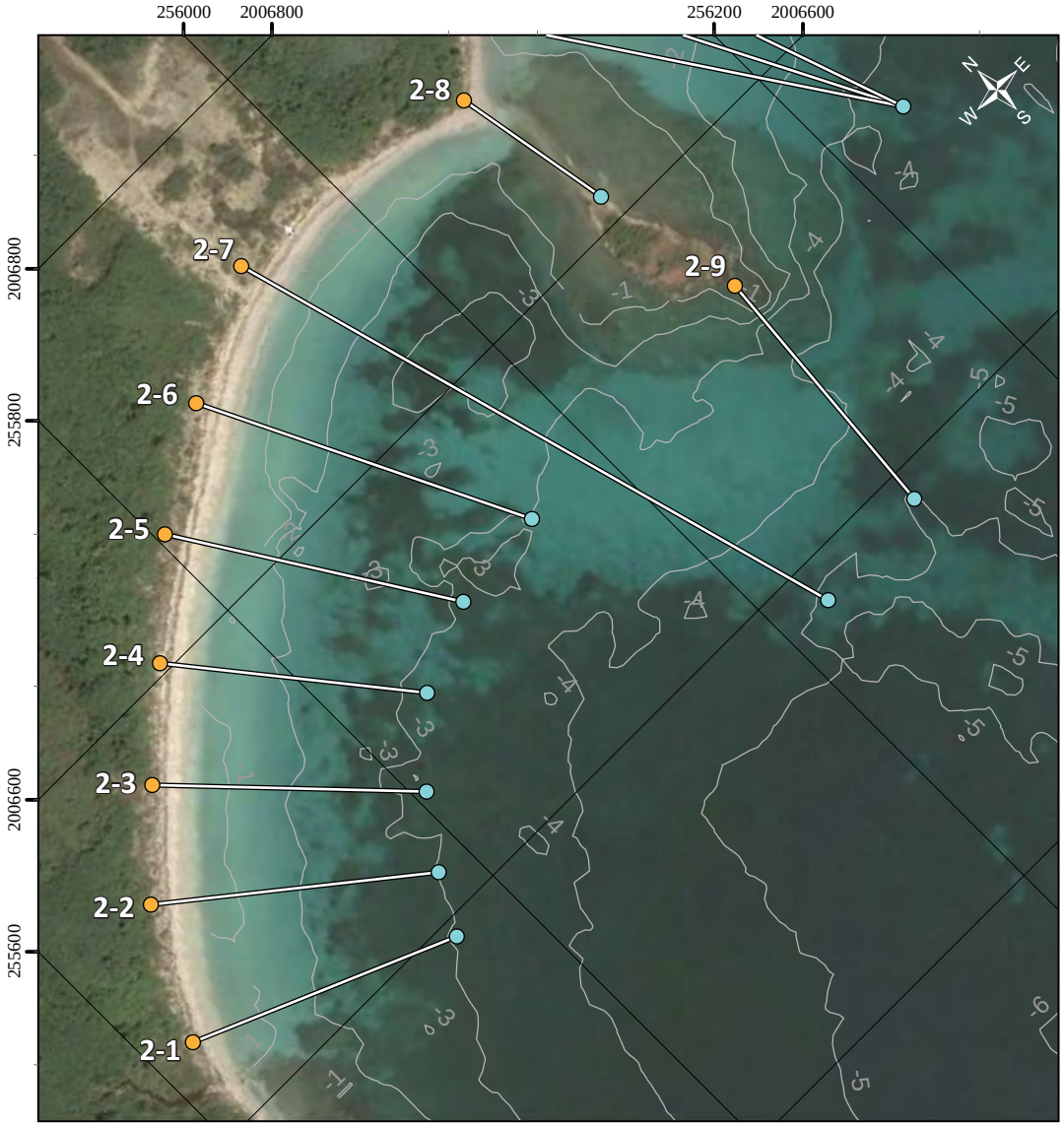


FIGURE D-10
Aerial View of Beach 19 (top) and a View of the Beach to the Northeast (bottom)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Aerial source 2017 Google Earth. Image U.S. Geological Survey.

FIGURE D-11
Aerial View of SWMU 4 (top) and West View of the Southwest-facing Beach (bottom)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Map and aerial sources: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, and IGP.



Beach 2 (Unnamed) Transect Map

		Easting	Northing	Length	Heading (°N) to Toe	Heading (°N) to Head
2-1	Head	255,624.19	2,006,450.31	151.5	113.2	293.2
	Toe	255,763.40	2,006,390.62			
2-2	Head	255,660.27	2,006,517.81	154.0	128.6	308.6
	Toe	255,780.71	2,006,421.80			
2-3	Head	255,705.58	2,006,562.50	146.2	136.4	316.4
	Toe	255,806.48	2,006,456.68			
2-4	Head	255,754.54	2,006,605.57	143.3	141.4	321.4
	Toe	255,843.99	2,006,493.64			
2-5	Head	255,805.03	2,006,652.29	163.1	147.8	327.8
	Toe	255,892.07	2,006,514.34			
2-6	Head	255,866.17	2,006,689.99	189.3	154.1	334.1
	Toe	255,948.92	2,006,519.74			
2-7	Head	255,934.79	2,006,724.74	360.2	164.7	344.7
	Toe	256,029.98	2,006,377.39			
2-8	Head	256,081.19	2,006,702.99	89.2	170.1	350.1
	Toe	256,096.57	2,006,615.10			
2-9	Head	256,113.20	2,006,531.13	148.4	184.8	4.8
	Toe	256,100.85	2,006,383.26			

0 40 80 160 Meters

LEGEND
- Transect line
- Head of transect
- Toe of transect
- Depth contour

NOTES
1. All dimensions are in meters.
2. Horizontal datum: NAD 1983 UTM 20N. Vertical datum: Mean Sea Level (MSL).

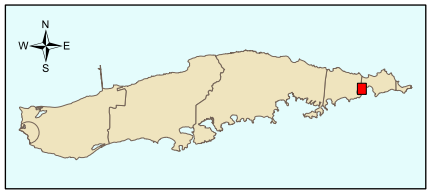


FIGURE D-12
Beach 2 Transects
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Map and aerial sources: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, and IGP.

Beach 3 (Playa Salina del Sur) Transect Map

		Easting	Northing	Length	Heading (°N)	
					to Toe	to Head
3-1	Head	256,111.12	2,006,735.03	240.2	146.3	326.3
	Toe	256,244.50	2,006,535.19			
3-2	Head	256,130.16	2,006,758.59	251.0	152.9	332.9
	Toe	256,244.50	2,006,535.19			
3-3	Head	256,164.87	2,006,763.91	242.2	160.8	340.8
	Toe	256,244.50	2,006,535.19			

0 20 40 80
Meters

LEGEND
- Transect line
- Head of transect
- Toe of transect
- Depth contour

NOTES
1. All dimensions are in meters.
2. Horizontal datum: NAD 1983 UTM 20N.
   Vertical datum: Mean Sea Level (MSL).

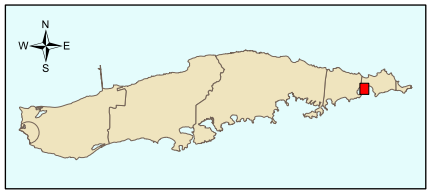
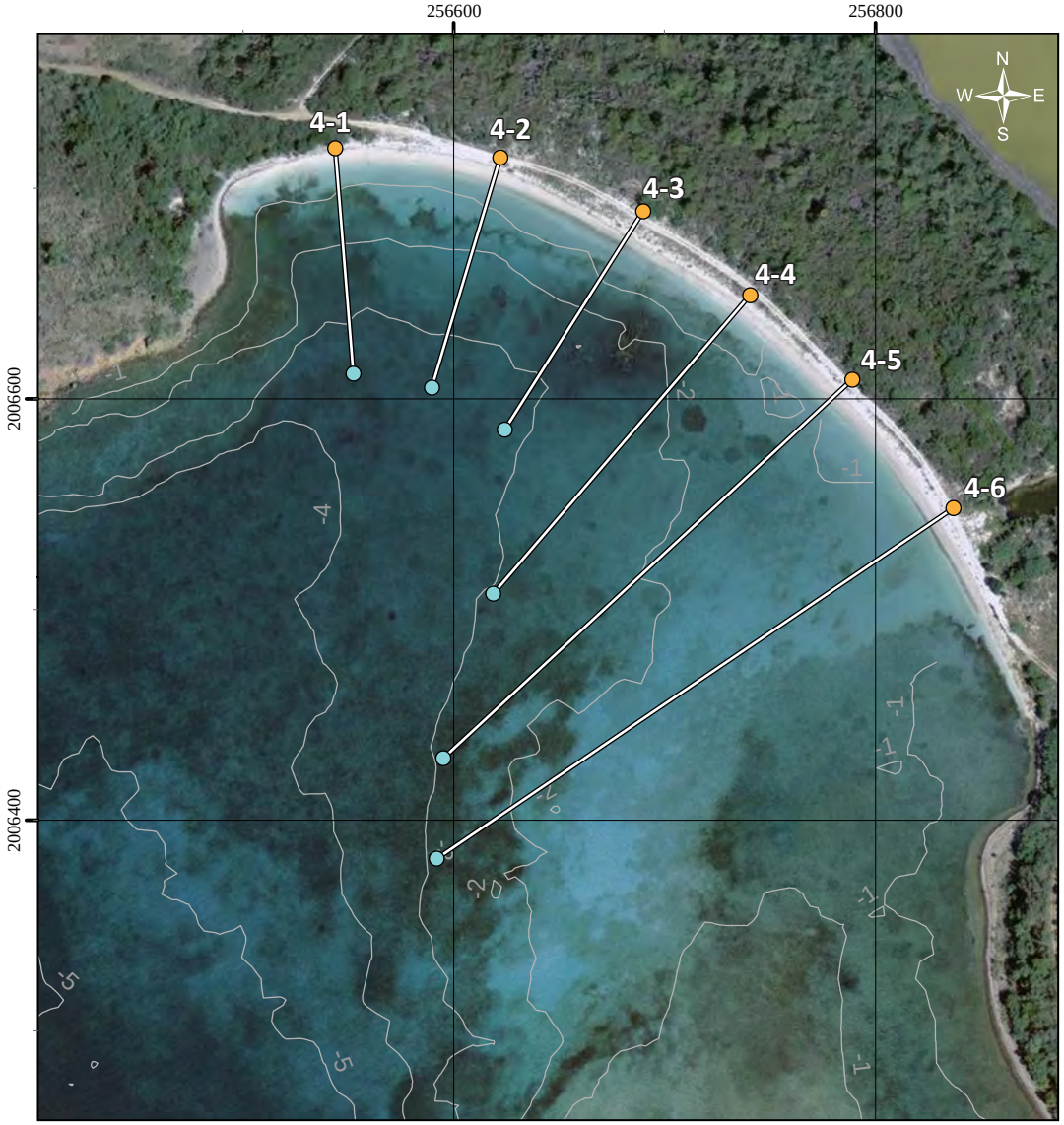


FIGURE D-13
Beach 3 Transects
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Map and aerial sources: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, and IGP.



Beach 4 (Turtle Beach/Playa Carrucho) Transect Map

		Easting	Northing	Length	Heading (°N)	
					to Toe	to Head
4-1	Head	256,543.77	2,006,718.89	107.2	175.4	355.4
	Toe	256,552.30	2,006,612.00			
4-2	Head	256,621.94	2,006,714.56	113.8	196.6	16.6
	Toe	256,589.41	2,006,605.50			
4-3	Head	256,689.66	2,006,689.03	122.6	212.3	32.3
	Toe	256,624.07	2,006,585.43			
4-4	Head	256,740.58	2,006,649.08	186.8	220.8	40.8
	Toe	256,618.61	2,006,507.57			
4-5	Head	256,788.81	2,006,609.01	264.1	227.2	47.2
	Toe	256,595.00	2,006,429.56			
4-6	Head	256,836.98	2,006,548.13	296.3	235.9	55.9
	Toe	256,591.76	2,006,381.84			

0 35 70 140 Meters

LEGEND
- Transect line
- Head of transect
- Toe of transect
- Depth contour

NOTES
1. All dimensions are in meters.
2. Horizontal datum: NAD 1983 UTM 20N. Vertical datum: Mean Sea Level (MSL).

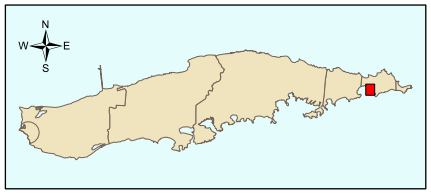
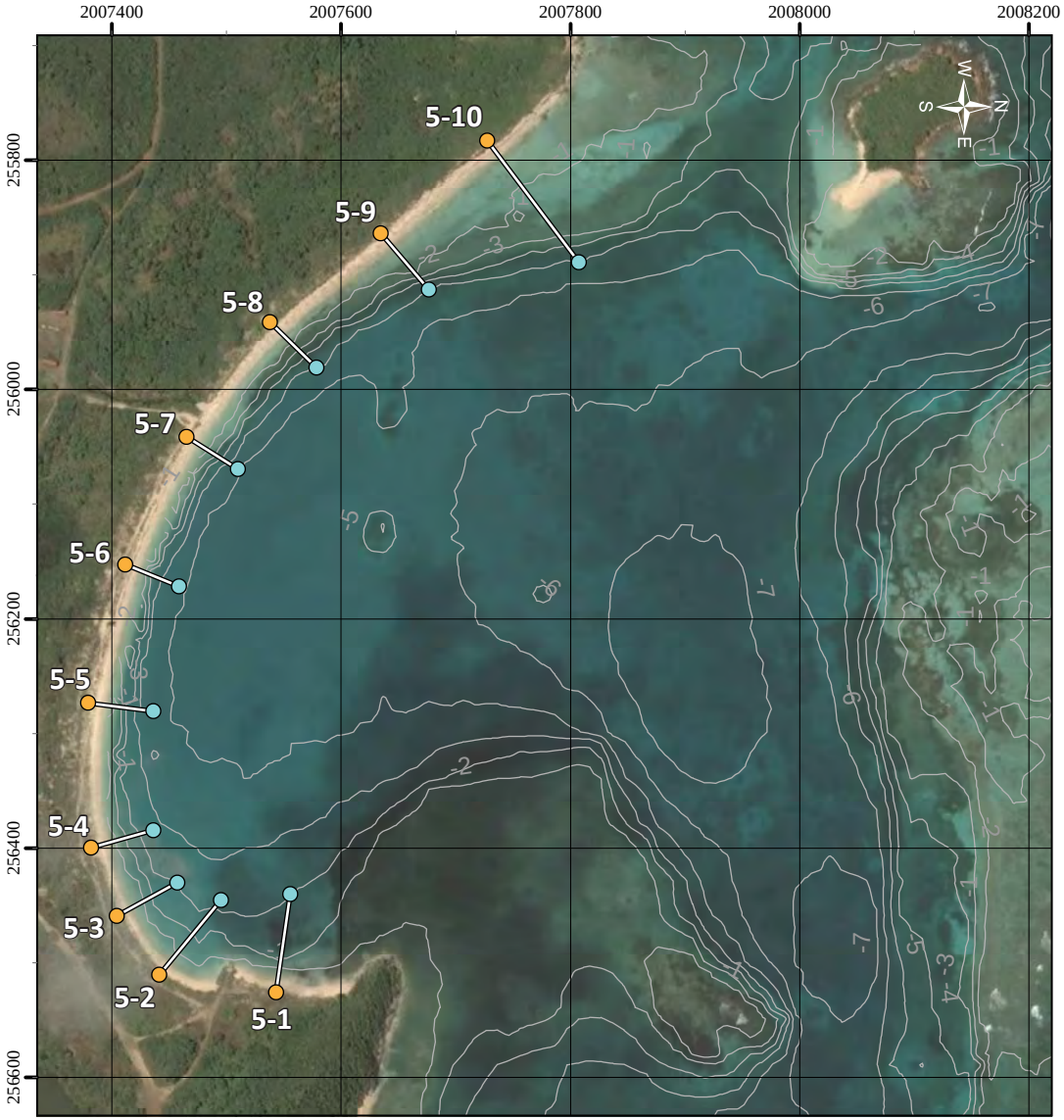


FIGURE D-14
Beach 4 Transects
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Map and aerial sources: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, and IGP.



Beach 5 (Icacos/Playa Yallis) Transect Map

		Easting	Northing	Length	Heading (°N) to Toe	Heading (°N) to Head
5-1	Head	256,525.65	2,007,543.07	86.6	278.2	98.2
	Toe	256,439.89	2,007,555.41			
5-2	Head	256,510.62	2,007,441.43	84.2	309.3	129.3
	Toe	256,445.44	2,007,494.80			
5-3	Head	256,459.25	2,007,403.95	60.6	331.0	151.0
	Toe	256,429.90	2,007,456.94			
5-4	Head	256,399.38	2,007,381.59	56.5	344.4	164.4
	Toe	256,384.18	2,007,436.05			
5-5	Head	256,273.59	2,007,379.14	57.3	6.8	186.8
	Toe	256,280.42	2,007,436.05			
5-6	Head	256,152.82	2,007,411.59	50.6	21.9	201.9
	Toe	256,171.66	2,007,458.55			
5-7	Head	256,041.32	2,007,464.85	52.9	31.8	211.8
	Toe	256,069.15	2,007,509.81			
5-8	Head	255,941.21	2,007,537.75	56.5	44.3	224.3
	Toe	255,980.65	2,007,578.17			
5-9	Head	255,863.75	2,007,634.61	64.4	49.6	229.6
	Toe	255,912.80	2,007,676.34			
5-10	Head	255,782.65	2,007,727.51	132.6	53.2	233.2
	Toe	255,888.77	2,007,807.04			

0 50 100 200 Meters

LEGEND
- Transect line
- Head of transect
- Toe of transect
- Depth contour

NOTES
1. All dimensions are in meters.
2. Horizontal datum: NAD 1983 UTM 20N. Vertical datum: Mean Sea Level (MSL).

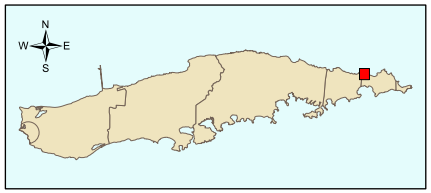
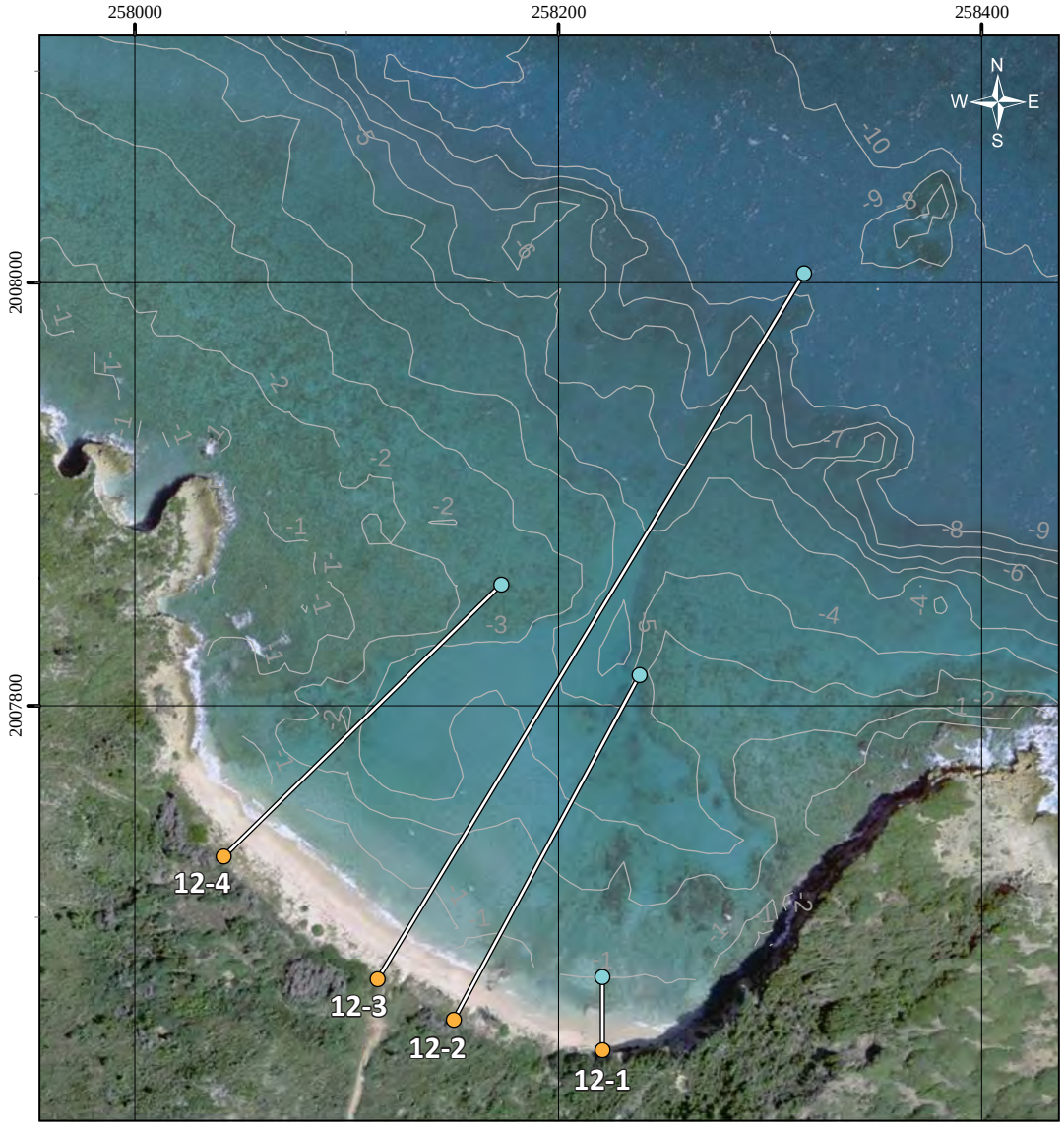


FIGURE D-15
Beach 5 Transects
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Map and aerial sources: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, and IGP.



Beach 12 (Unnamed) Transect Map

		Easting	Northing	Length	Heading (°N)	
					to Toe	to Head
12-1	Head	258,220.83	2,007,637.35	34.4	0.1	180.1
	Toe	258,220.90	2,007,671.72			
12-2	Head	258,150.74	2,007,651.60	185.1	28.3	208.3
	Toe	258,238.55	2,007,814.56			
12-3	Head	258,114.68	2,007,670.74	389.8	31.1	211.1
	Toe	258,316.21	2,008,004.40			
12-4	Head	258,041.81	2,007,728.77	183.5	45.6	225.6
	Toe	258,172.88	2,007,857.14			

0 25 50 100 Meters

LEGEND
- Transect line
- Head of transect
- Toe of transect
- Depth contour

NOTES
1. All dimensions are in meters.
2. Horizontal datum: NAD 1983 UTM 20N. Vertical datum: Mean Sea Level (MSL).

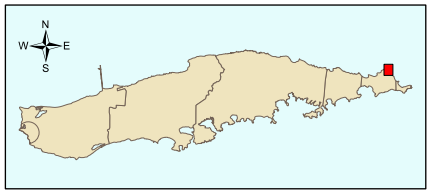
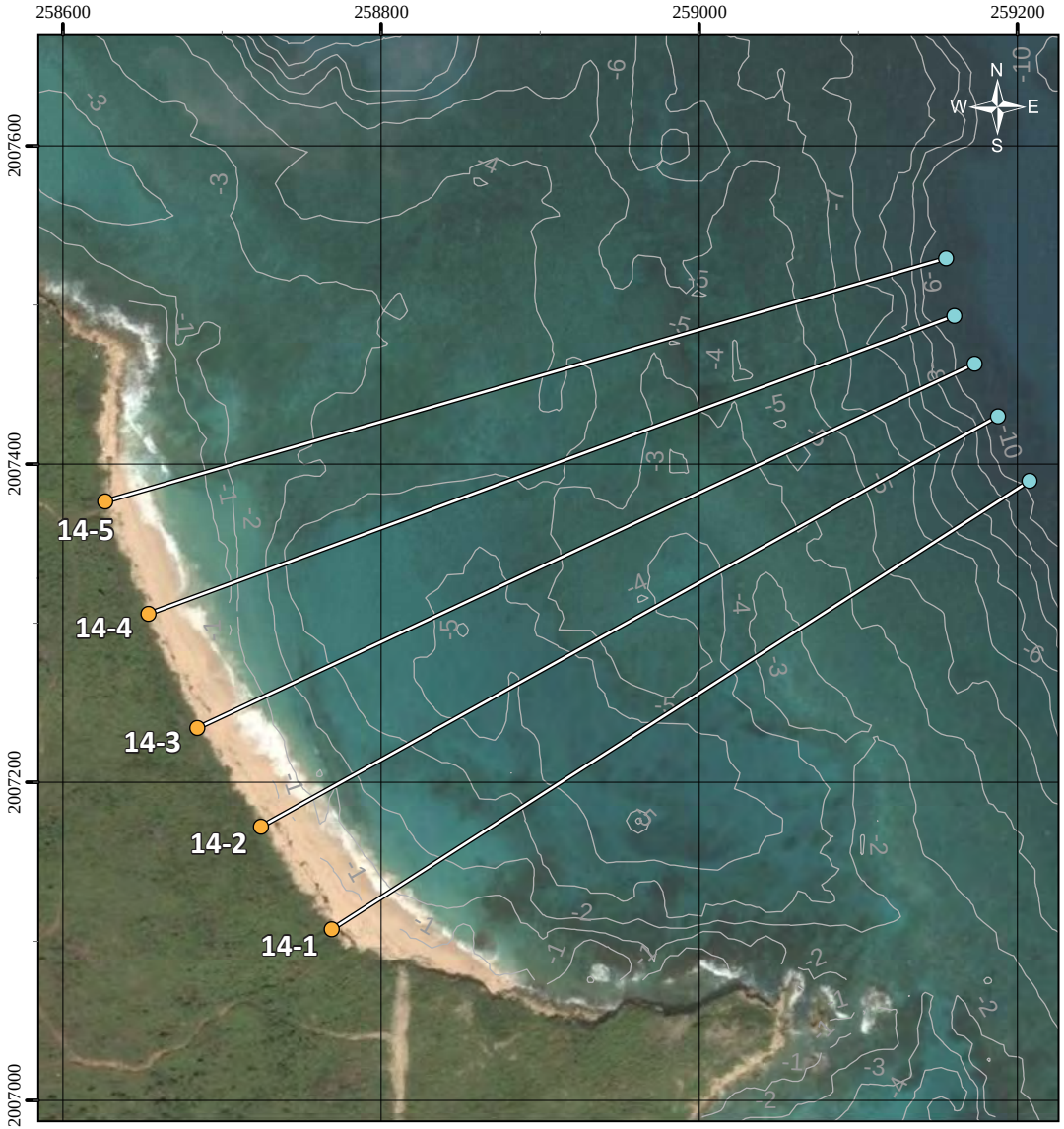


FIGURE D-16
Beach 12 Transects
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Map and aerial sources: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, and IGP.



Beach 14 (Playa Brava) Transect Map

		Easting	Northing	Length	Heading (°N)	
					to Toe	to Head
14-1	Head	258,768.88	2,007,107.66	521.5	57.3	237.3
	Toe	259,207.71	2,007,389.43			
14-2	Head	258,724.31	2,007,172.26	530.1	60.9	240.9
	Toe	259,187.45	2,007,430.12			
14-3	Head	258,684.43	2,007,234.32	539.8	64.9	244.9
	Toe	259,173.24	2,007,463.35			
14-4	Head	258,653.67	2,007,305.88	540.4	69.7	249.7
	Toe	259,160.51	2,007,493.41			
14-5	Head	258,626.31	2,007,376.65	550.6	73.9	253.9
	Toe	259,155.24	2,007,529.52			

0 50 100 200 Meters

LEGEND
- Transect line
- Head of transect
- Toe of transect
- Depth contour

NOTES
1. All dimensions are in meters.
2. Horizontal datum: NAD 1983 UTM 20N. Vertical datum: Mean Sea Level (MSL).

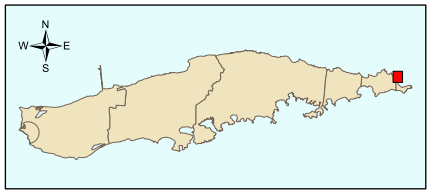
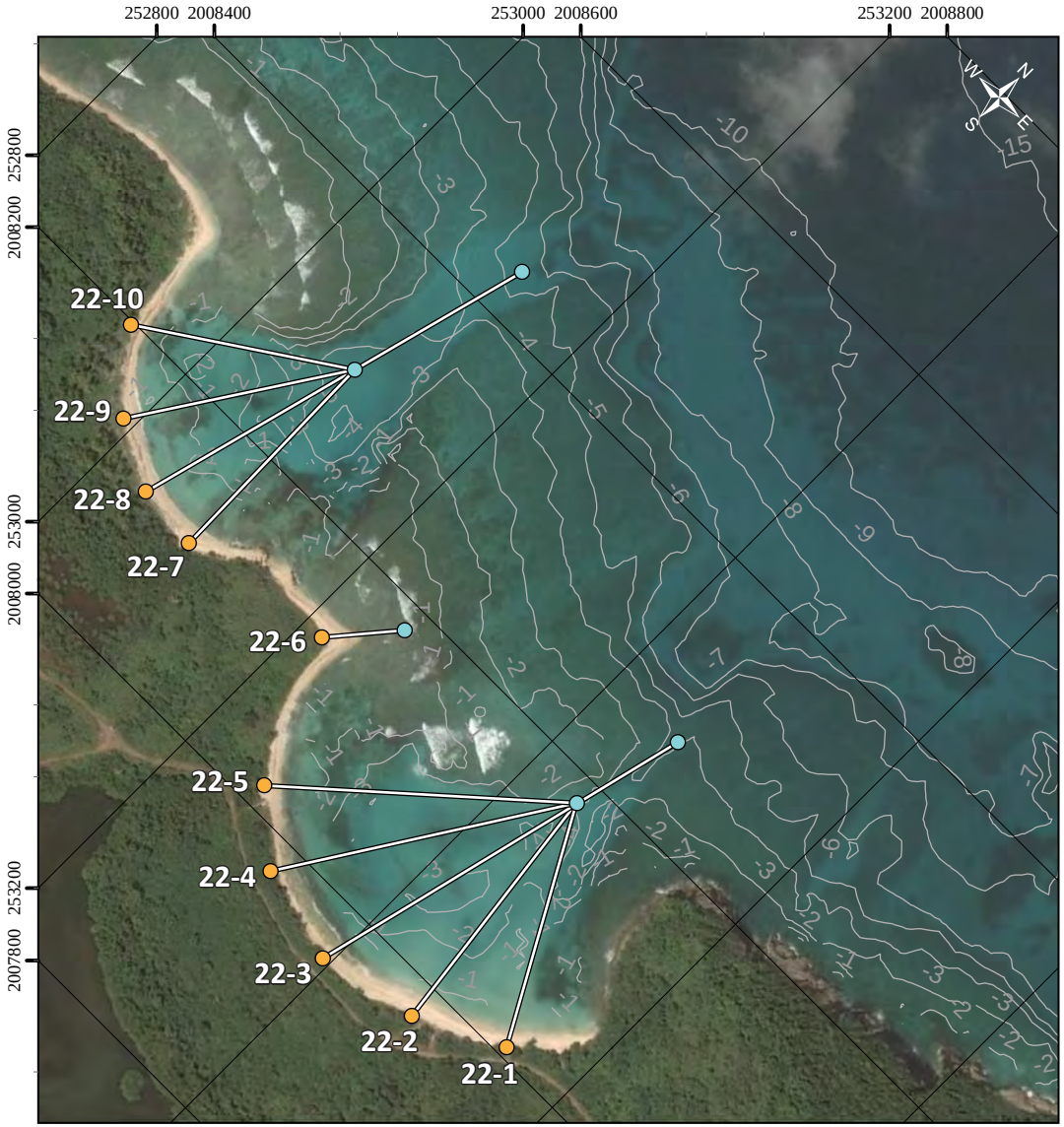


FIGURE D-17
Beach 14 Transects
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Map and aerial sources: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, and IGP.



Beach 22 (Puerto Diablo) Transect Map

		Easting	Northing	Length	Heading (°N) to Toe	Heading (°N) to Head
22-1	Head	253,542.26	2,008,008.12	196.1	331.0	151.0
	Toe	253,447.08	2,008,179.54			
22-2	Head	253,473.39	2,007,973.26	208.0	352.7	172.7
	Toe	253,447.08	2,008,179.54			
22-3	Head	253,393.56	2,007,956.33	320.7	13.7	193.7
	Toe	253,469.24	2,008,267.94			
22-4	Head	253,317.42	2,007,975.69	241.6	32.5	212.5
	Toe	253,447.08	2,008,179.54			
22-5	Head	253,267.23	2,008,018.90	241.1	48.2	228.2
	Toe	253,447.08	2,008,179.54			
22-6	Head	253,217.97	2,008,131.05	63.8	39.9	219.9
	Toe	253,258.93	2,008,179.96			
22-7	Head	253,093.70	2,008,109.90	184.9	358.8	178.8
	Toe	253,089.79	2,008,294.79			
22-8	Head	253,042.63	2,008,114.73	335.9	14.7	194.7
	Toe	253,127.95	2,008,439.58			
22-9	Head	252,990.37	2,008,142.51	181.9	33.1	213.1
	Toe	253,089.79	2,008,294.79			
22-10	Head	252,942.86	2,008,197.42	176.3	56.5	236.5
	Toe	253,089.79	2,008,294.79			

0 50 100 200 Meters

LEGEND
- Transect line
- Head of transect
- Toe of transect
- Depth contour

NOTES
1. All dimensions are in meters.
2. Horizontal datum: NAD 1983 UTM 20N. Vertical datum: Mean Sea Level (MSL).

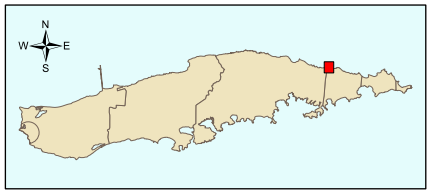
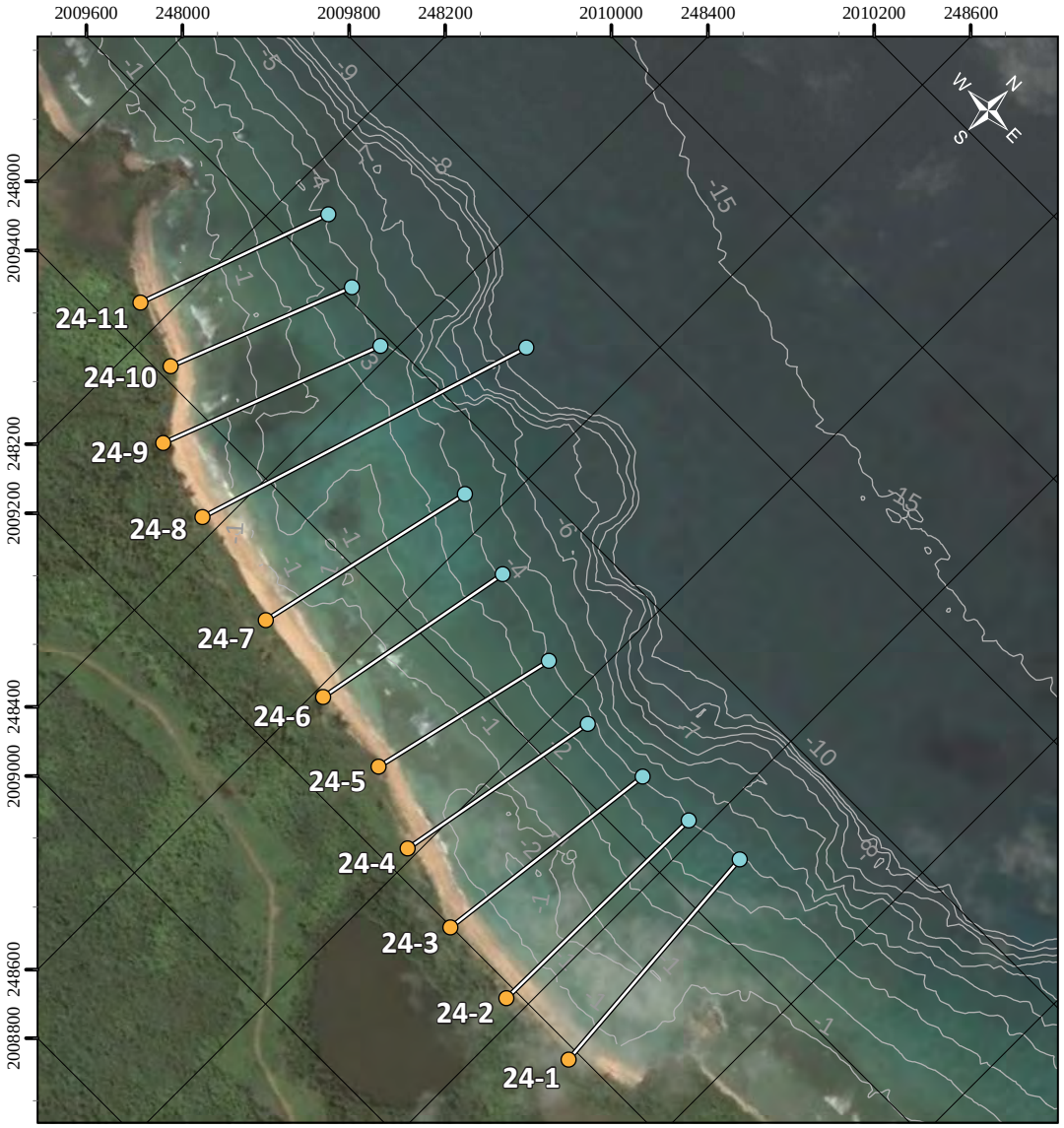


FIGURE D-18
Beach 22 Transects
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Map and aerial sources: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, and IGP.



Beach 24 (Purple Beach/Playa Campaña) Transect Map

		Easting	Northing	Length	Heading (°N) to Toe	Heading (°N) to Head
24-1	Head	249,072.96	2,009,188.48	283.3	355.5	175.5
	Toe	249,050.58	2,009,470.86			
24-2	Head	248,979.15	2,009,187.92	273.7	0.7	180.7
	Toe	248,982.41	2,009,461.62			
24-3	Head	248,882.40	2,009,199.09	262.9	6.8	186.8
	Toe	248,913.58	2,009,460.16			
24-4	Head	248,790.02	2,009,226.51	235.7	10.3	190.3
	Toe	248,832.26	2,009,458.38			
24-5	Head	248,705.36	2,009,266.54	216.0	13.1	193.1
	Toe	248,754.27	2,009,476.95			
24-6	Head	248,610.05	2,009,277.87	233.6	10.6	190.6
	Toe	248,653.21	2,009,507.41			
24-7	Head	248,508.14	2,009,292.16	253.9	12.6	192.6
	Toe	248,563.47	2,009,540.00			
24-8	Head	248,381.22	2,009,322.78	393.5	17.4	197.4
	Toe	248,498.92	2,009,698.31			
24-9	Head	248,294.87	2,009,349.28	256.2	20.9	200.9
	Toe	248,386.35	2,009,588.59			
24-10	Head	248,242.04	2,009,413.63	212.3	21.4	201.4
	Toe	248,319.44	2,009,611.37			
24-11	Head	248,170.73	2,009,438.71	223.4	19.7	199.7
	Toe	248,246.06	2,009,649.04			

0 75 150 300 Meters

LEGEND
- Transect line
- Head of transect
- Toe of transect
- Depth contour

NOTES
1. All dimensions are in meters.
2. Horizontal datum: NAD 1983 UTM 20N. Vertical datum: Mean Sea Level (MSL).

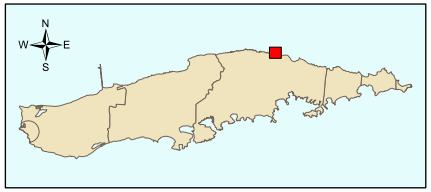
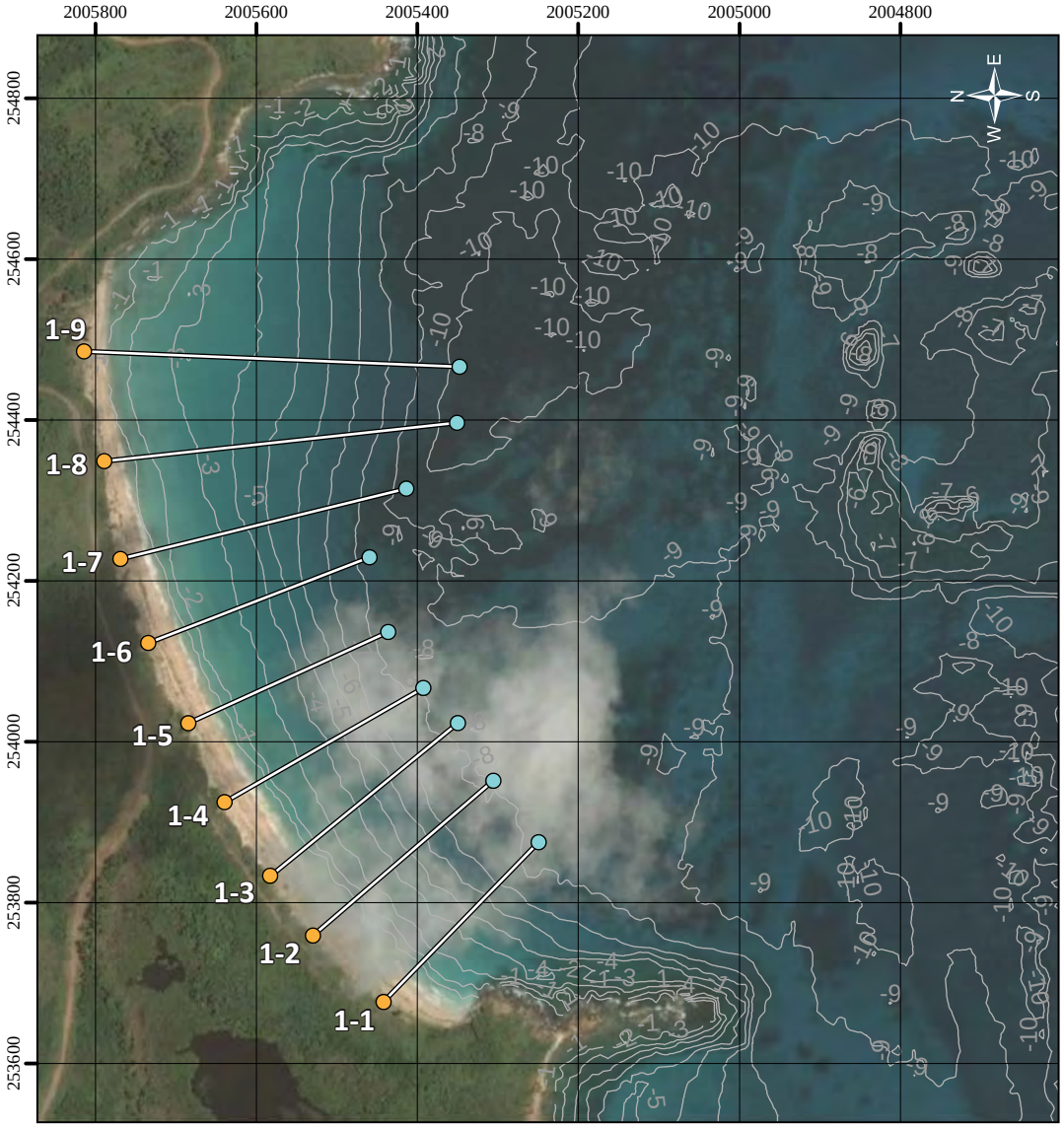


FIGURE D-19
Beach 24 Transects
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Map and aerial sources: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, and IGP.



Beach 1 (Yellow Beach/Playa Matías) Transect Map

		Easting	Northing	Length	Heading (°N)	
					to Toe	to Head
1-1	Head	253,676.40	2,005,442.44	277.2	134.1	314.1
	Toe	253,875.32	2,005,249.41			
1-2	Head	253,759.20	2,005,530.02	295.1	139.3	319.3
	Toe	253,951.69	2,005,306.29			
1-3	Head	253,832.64	2,005,582.81	301.0	140.7	320.7
	Toe	254,023.07	2,005,349.73			
1-4	Head	253,924.80	2,005,639.47	284.8	150.1	330.1
	Toe	254,066.86	2,005,392.65			
1-5	Head	254,023.04	2,005,685.03	273.6	155.5	335.5
	Toe	254,136.69	2,005,436.19			
1-6	Head	254,122.75	2,005,734.22	294.3	158.8	338.8
	Toe	254,229.23	2,005,459.83			
1-7	Head	254,227.24	2,005,769.37	366.3	166.2	346.2
	Toe	254,314.65	2,005,413.70			
1-8	Head	254,348.84	2,005,788.83	440.0	173.8	353.8
	Toe	254,396.45	2,005,351.36			
1-9	Head	254,485.32	2,005,814.08	466.8	182.4	2.4
	Toe	254,466.09	2,005,347.70			

0 100 200 400 Meters

LEGEND
- Transect line
- Head of transect
- Toe of transect
- Depth contour

NOTES
1. All dimensions are in meters.
2. Horizontal datum: NAD 1983 UTM 20N. Vertical datum: Mean Sea Level (MSL).

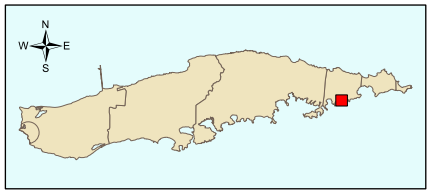
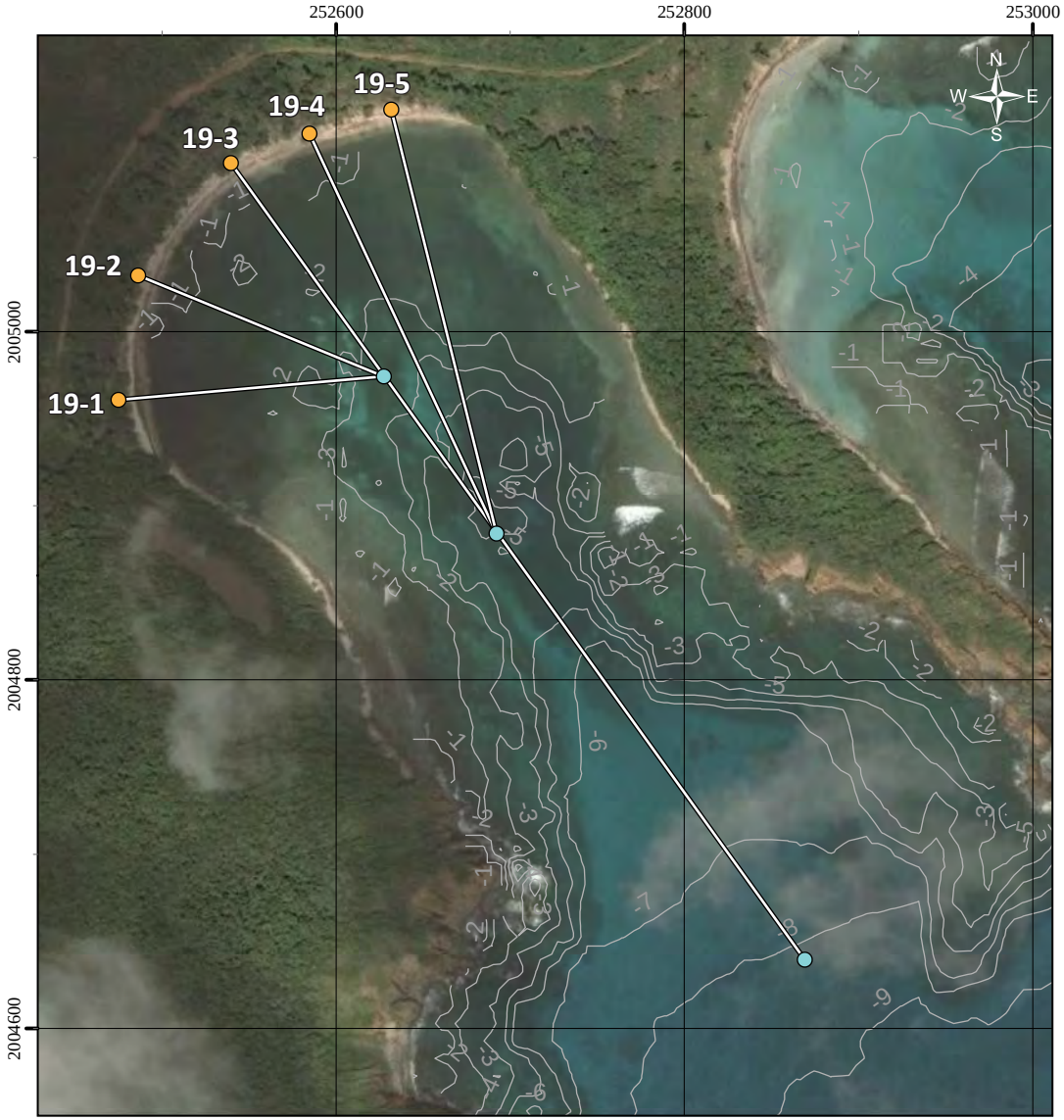


FIGURE D-20
Beach 1 Transects
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Map and aerial sources: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, and IGP.



Beach 19 (Playa Yoyé) Transect Map

		Easting	Northing	Length	Heading (°N) to Toe	Heading (°N) to Head
19-1	Head	252,475.15	2,004,960.88	152.7	85.0	265.0
	Toe	252,627.28	2,004,974.24			
19-2	Head	252,486.45	2,005,032.10	152.3	112.3	292.3
	Toe	252,627.28	2,004,974.24			
19-3	Head	252,539.52	2,005,096.61	563.4	144.2	324.2
	Toe	252,868.93	2,004,639.59			
19-4	Head	252,584.60	2,005,113.55	253.4	154.9	334.9
	Toe	252,692.24	2,004,884.12			
19-5	Head	252,631.71	2,005,127.52	250.8	166.0	346.0
	Toe	252,692.24	2,004,884.12			

0 37.5 75 150 Meters

LEGEND
- Transect line
- Head of transect
- Toe of transect
- Depth contour

NOTES
1. All dimensions are in meters.
2. Horizontal datum: NAD 1983 UTM 20N. Vertical datum: Mean Sea Level (MSL).

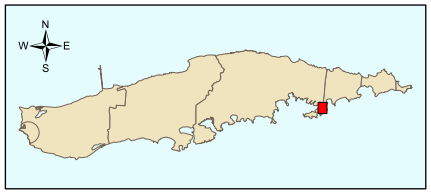
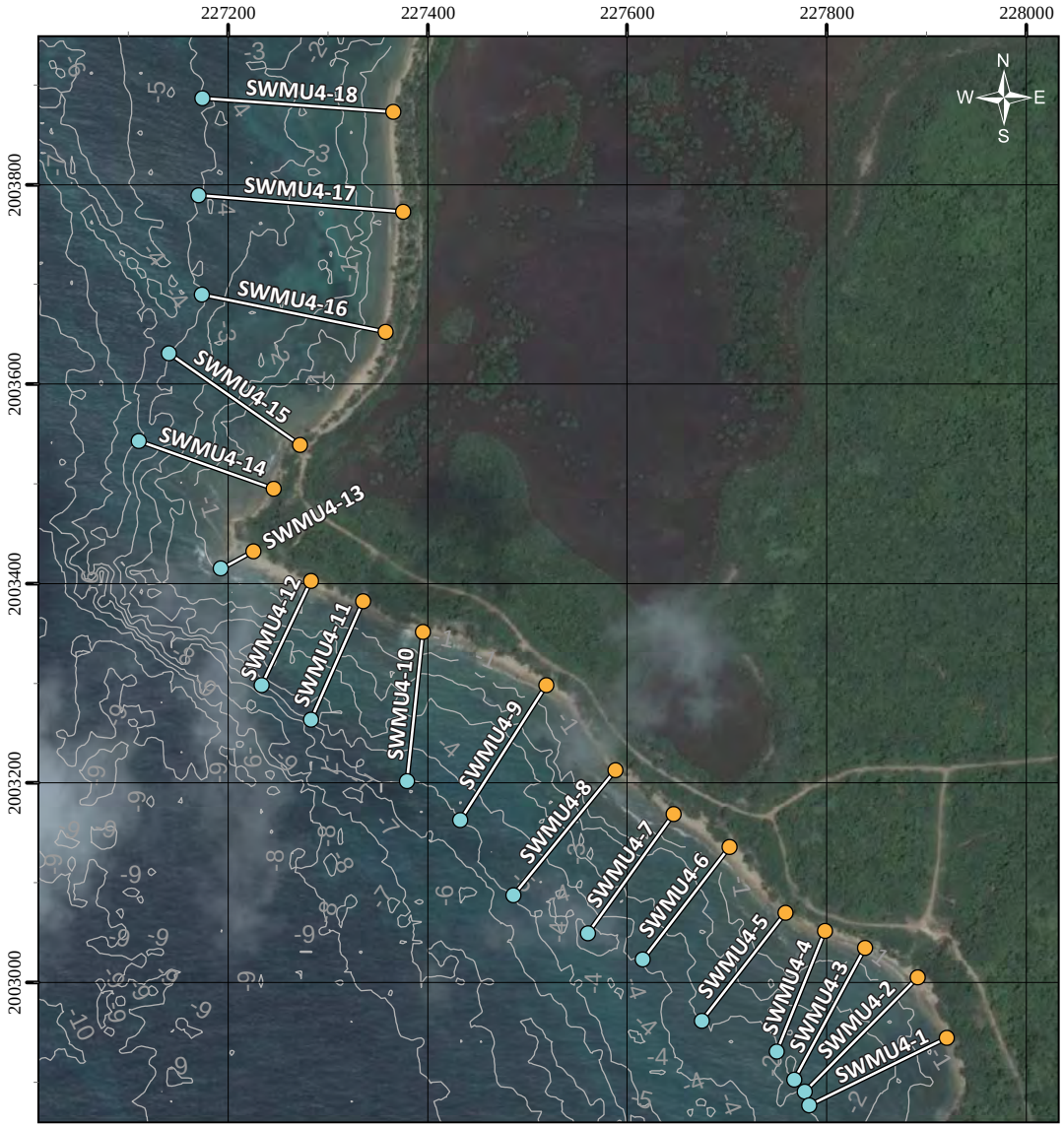


FIGURE D-21
Beach 19 Transects
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Map and aerial sources: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, and IGP.



Beach SWMU 4 Transect Map

		Easting	Northing	Length	Heading (°N) to Toe	Heading (°N) to Head
SWMU4-1	Head	227,920.54	2,002,944.53	153.9	243.9	63.9
	Toe	227,782.34	2,002,876.85			
SWMU4-2	Head	227,891.35	2,003,005.03	161.1	224.9	44.9
	Toe	227,777.71	2,002,890.86			
SWMU4-3	Head	227,838.36	2,003,034.53	149.8	208.3	28.3
	Toe	227,767.44	2,002,902.54			
SWMU4-4	Head	227,798.47	2,003,051.63	130.3	201.9	21.9
	Toe	227,749.81	2,002,930.75			
SWMU4-5	Head	227,758.99	2,003,069.98	137.5	217.9	37.9
	Toe	227,674.49	2,002,961.54			
SWMU4-6	Head	227,702.39	2,003,135.72	142.0	217.6	37.6
	Toe	227,615.74	2,003,023.16			
SWMU4-7	Head	227,646.54	2,003,169.00	147.1	215.6	35.6
	Toe	227,560.95	2,003,049.42			
SWMU4-8	Head	227,588.35	2,003,212.90	161.9	219.4	39.4
	Toe	227,485.67	2,003,087.74			
SWMU4-9	Head	227,518.73	2,003,298.00	160.0	212.5	32.5
	Toe	227,432.85	2,003,162.95			
SWMU4-10	Head	227,395.45	2,003,351.77	150.6	186.1	6.1
	Toe	227,379.44	2,003,201.99			
SWMU4-11	Head	227,335.12	2,003,382.04	129.3	203.7	23.7
	Toe	227,283.17	2,003,263.60			
SWMU4-12	Head	227,282.95	2,003,402.54	115.5	205.4	25.4
	Toe	227,233.47	2,003,298.15			
SWMU4-13	Head	227,225.08	2,003,432.23	35.5	241.3	61.3
	Toe	227,193.95	2,003,415.22			
SWMU4-14	Head	227,245.71	2,003,495.09	143.9	289.5	109.5
	Toe	227,110.07	2,003,543.07			
SWMU4-15	Head	227,271.79	2,003,539.09	160.3	305.0	125.0
	Toe	227,140.47	2,003,631.02			
SWMU4-16	Head	227,357.64	2,003,652.26	187.9	281.6	101.6
	Toe	227,173.52	2,003,689.99			
SWMU4-17	Head	227,375.41	2,003,772.68	205.8	274.6	94.6
	Toe	227,170.25	2,003,789.09			
SWMU4-18	Head	227,365.52	2,003,872.90	192.2	274.2	94.2
	Toe	227,173.83	2,003,886.84			

0 100 200 400 Meters

LEGEND

- Transect line
- Head of transect
- Toe of transect
- Depth contour

NOTES

1. All dimensions are in meters.
2. Horizontal datum: NAD 1983 UTM 20N. Vertical datum: Mean Sea Level (MSL).

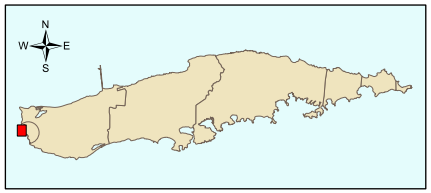


FIGURE D-22
Beach SWMU 4 Transects
Beach Dynamics Investigation Report
Vieques, Puerto Rico

FIGURE D-23
Survey Boat Ready for Launching
Beach Dynamics Investigation Report
Vieques, Puerto Rico

FIGURE D-24
Land Crew Surveying Beach
Beach Dynamics Investigation Report
Vieques, Puerto Rico

FIGURE D-25
Beach Transect View, Shoreline Marker (orange cone) on the Left and Transect Head Marker (wooden stake) on the Right at the Edge of Vegetation, Cerro Matias Jalobre and OP1 in the Background (Beach 2 Transect 4, April 8, 2016)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

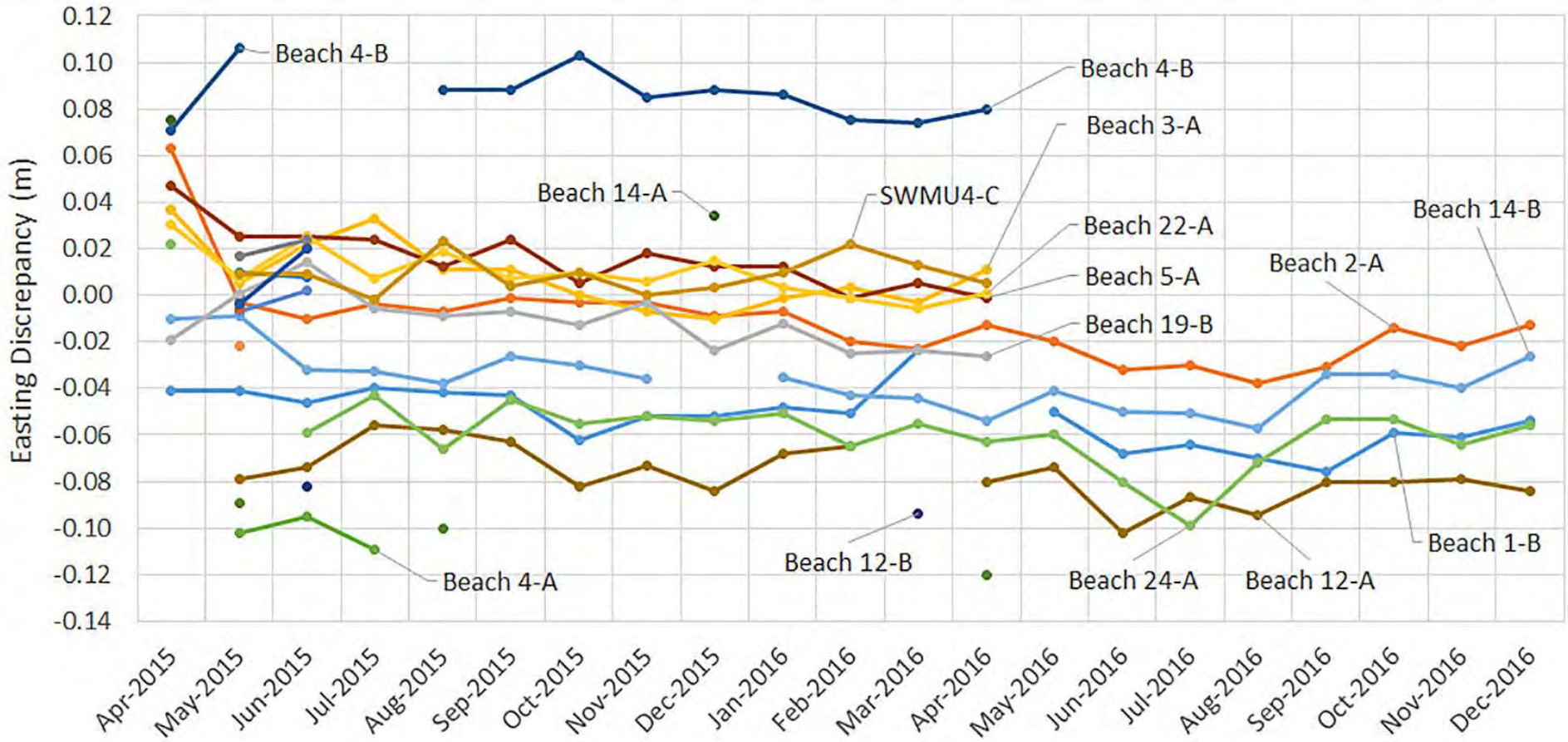


FIGURE D-26
History of Easting Discrepancies of Land GPS Rover Receiver (acquired – target)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

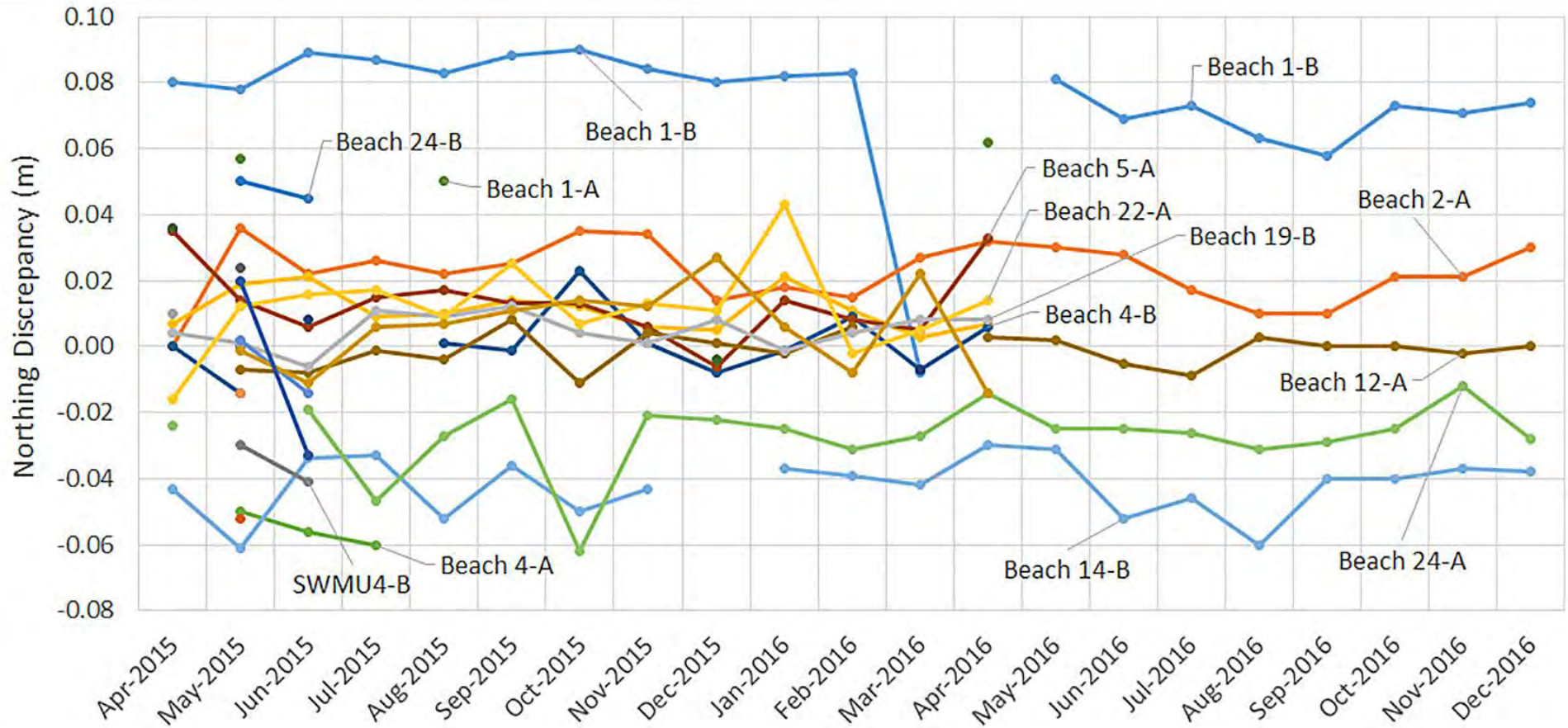


FIGURE D-27
History of Northing Discrepancies of Land GPS Rover Receiver (acquired – target)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

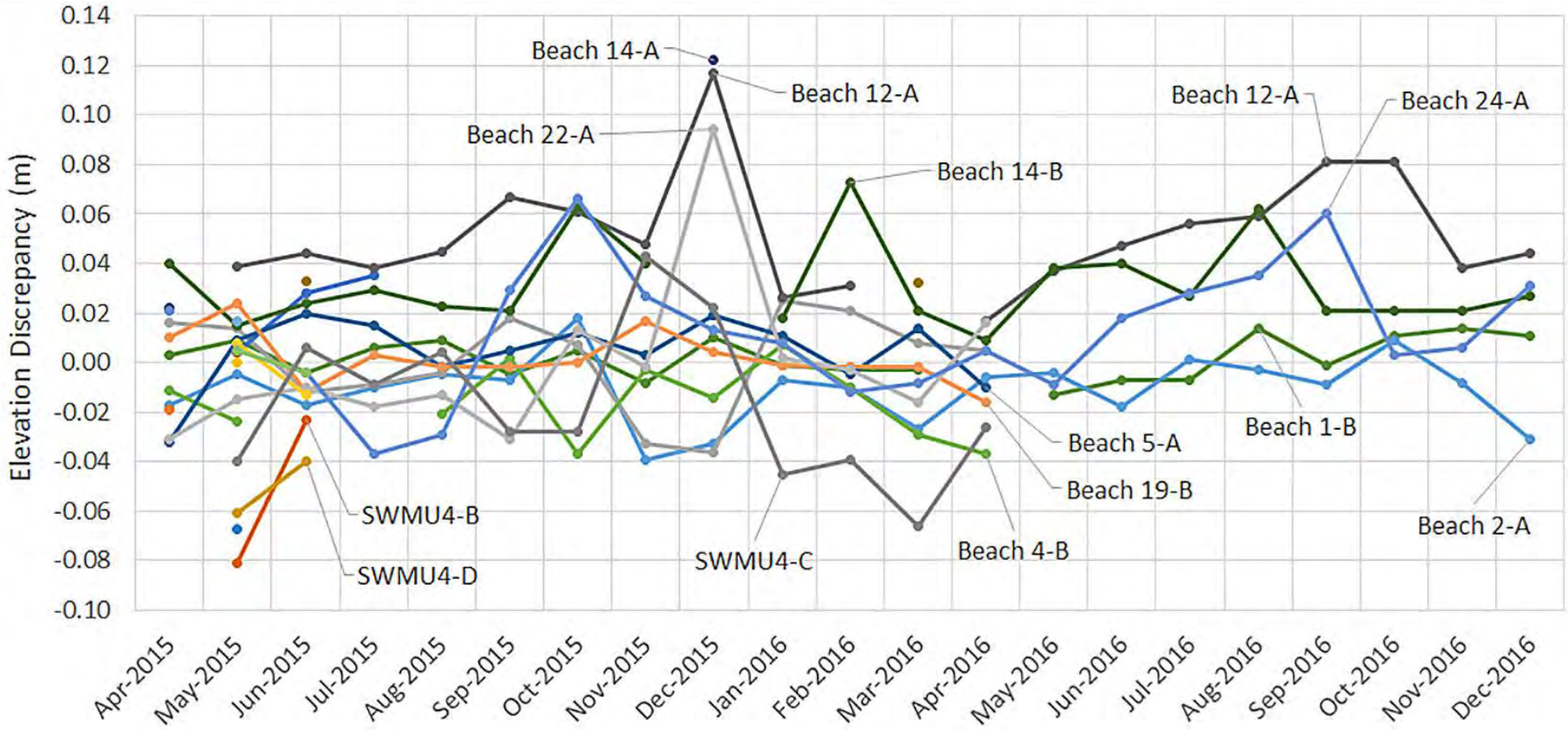


FIGURE D-28
History of Elevation Discrepancies of (land and water)
GPS Rover Receivers (acquired – target)
Beach Dynamics Investigation Report
Vieques, Puerto Rico

Appendix E
Sediment Sampling

APPENDIX E

Sediment Sampling and Analysis

Samples of beach sediment and nearshore bottom were collected approximately quarterly for the first year at each of the 11 beaches selected for the Beach Dynamics Investigation (BDI). The samples were collected at 3 locations along selected transects at each beach: at the backshore, shoreline, and nearshore. Samples were collected during the beach surveys as follows:

1. April/May 2015
2. August 2015
3. November 2015
4. February 2016

Sample locations, sampling procedures, and data analysis are described in the following sections.

1. Sample Locations

Figure E-1 through **Figure E-6** show the transects, shoreline, and locations of the samples collected at Live Impact Area (LIA) UXO 2 Beaches 2, 3, 4, 5, 12, and 14 in April 2015; **Figure E-7** through **Figure E-9** for Eastern Maneuver Area (EMA) and Surface Impact Area (SIA) Beaches 22 and 24; **Figure E-10** and **Figure E-11**for South SIA UXO 8 Beaches 1 and 19; and **Figure E-12** and **Figure E-13** for Solid Waste Management Unit (SWMU) 4 in May 2015.

Samples were collected along two transects at Beach 22 (east and west) and at the SWMU 4 beach (north and south) to characterize sediments at each side of the headlands dividing these beaches. **Table E-1** lists corresponding coordinates and elevations. For simplicity, the backshore location was designated location A, the shoreline location B, and the nearshore location C.

Temporal sediment samples were collected as close to the same locations as practical, based on external factors such as wave breaking, varying water levels at the shoreline locations, and waves/boat movement at the nearshore locations.

2. Sampling Procedure

The sediment sampling was performed in conjunction with the beach surveys according to the following procedure. Land and boat crews:

1. Located sample location on the selected transect
2. Collected samples: land crew in the backshore and shoreline, boat crew in the nearshore
3. Stored samples in laboratory provided containers
4. Labeled containers with sample id: beach-transect-sample location (a, b, or c), date/time/staff
5. Documented date/time/staff, sample id, and location in field notebook
6. Shipped samples along with the chain-of-custody to TestAmerica Laboratories, Inc.

Table E-1. Coordinates and Elevations of First Sediment Samples Collected in April 2015

Beach	Transect	Backshore (A)		Nearshore (C)	
		Location (E - N)	Elevation	Location (E - N)	Elevation
1	1-5	254,034 - 2,005,661	1.22	254,085 - 2,005,550	-5.2
2	2-4	255,760 - 2,006,602	0.82	255,795 - 2,006,555	-1.8
3	3-2	256,137 - 2,006,745	0.72	256,191 - 2,006,638	-1.5
4	4-2	256,620 - 2,006,708	0.88	256,613 - 2,006,693	-1.5
5	5-7	256,043 - 2,007,468	0.70	256,058 - 2,007,491	-2.1
12	12-3	258,121 - 2,007,681	1.64	258,184 - 2,007,786	-2.4
14	14-2	258,731 - 2,007,176	2.66	258,884 - 2,007,262	-4.0
19	19-3	252,544 - 2,005,092	0.80	252,795 - 2,004,742	-8.2
22	22-2	253,473 - 2,007,976	1.48	253,455 - 2,008,112	-2.4
	22-8	253,043 - 2,008,118	1.47	253,065 - 2,008,195	-2.1
24	24-8	248,384 - 2,009,330	1.97	248,443 - 2,009,506	-3.0
SWMU 4	SWMU4-6	227,696 - 2,003,128	0.87	227,667 - 2,003,088	-3.0
	SWMU4-17	227,368 - 2,003,773	0.93	227,332 - 2,003,775	-1.5

Coordinates in meters (m), Universal Transverse Mercator (UTM) 20 N NAD83
Elevations in m, Puerto Rico Vertical Datum 2002 (PRVD02)
Shoreline samples (B) were collected at variable locations on the transect and the shoreline
First SWMU 4 samples collected in May 2015

3. Analysis

Upon receipt of the samples, TestAmerica performed grain size analyses following the ASTM D422 method and submitted corresponding results in the form of tables and graphs of percentages of grain size, and percentages of gravel, sand (coarse, medium, and fine), and fines for each sample.

TestAmerica results were post-processed to compute grain size parameters such as D_{10}, D_{50}, D_{90}, D_{90}/D_{10}, D_{90}-D_{10}, D_{75}/D_{25}, and D_{75}-D_{25} using Gradistat version 8.0, a freely available grain size distribution and statistics package for the analysis of unconsolidated sediments by sieving or laser granulometer developed by Blott et al. (2001).

Results of the sediment analysis are included as an attachment to this Appendix.

4. References

Blott, S.J. and K. Pye. 2001. GRADISTAT: *A grain size distribution and statistics package for the analysis of unconsolidated sediments. Technical Communication*. Earth Surface Processes and Landforms, 26, 1237-1248.

Attachment

Sediment Analysis - Beach 2

Sample ID		2-4-A	2-4-B	2-4-C	2-4-A	2-4-B	2-4-C	2-4-A	2-4-B	2-4-C	2-4-A	2-4-B	2-4-C
Sample Date		4/2/15	4/2/15	4/2/15	8/13/15	8/13/15	8/17/15	11/17/15	11/17/15	11/17/15	2/9/16	2/9/16	2/9/16
Grain Size (PCT_P and PCT)													
GS03 SIEVE 3" (75 MM)	75000	100	100	100	100	100	100	100	100	100	100	100	100
GS05 SIEVE 2" (50 MM)	50000	100	100	100	100	100	100	100	100	100	100	100	100
GS06 SIEVE 1.5" (37.5 MM)	37500	100	100	100	100	100	100	100	100	100	100	100	100
GS07 SIEVE 1" (25.0 MM)	25000	100	100	100	100	100	100	100	100	100	100	100	100
GS08 SIEVE 0.75" (19.0 MM)	19000	100	100	100	100	100	100	100	100	100	100	100	100
GS10 SIEVE 0.375" (9.5 MM)	9500	100	100	100	100	100	100	100	100	100	100	100	100
SIEVE NO. 004 (4.75 MM)	4750	100	100	100	100	100	100	100	100	100	100	100	100
SIEVE NO. 010 (2.00 MM)	2000	99.9	100	99.9	99.9	99.9	99.8	99.8	99.7	100	99.9	100	100
SIEVE NO. 020 (850 UM)	850	99.5	97.4	99.4	99.8	98.7	99.5	99.8	98	99.9	99.6	99.7	99.8
SIEVE NO. 040 (425 UM)	425	95.9	85.7	98.4	99.7	95.1	98.7	99.5	93	99.5	97.6	97.7	99.1
SIEVE NO. 060 (250 UM)	250	79.2	74.6	95.5	97.2	87.6	97	95.6	84.1	98.1	85.1	88.2	96.4
SIEVE NO. 080 (180 UM)	180	52.7	70.3	90.9	78.8	75.5	93.7	75.2	67.7	94.7	59.5	67.2	90.9
SIEVE NO. 100 (150 UM)	150	31.4	45.4	84.4	42.5	60.6	88	44.6	48.9	89.4	37.9	45.7	82.8
SIEVE NO. 200 (75 UM)	75	3.8	20.1	14.3	2.5	5.9	14.8	3.3	2.2	13.9	1.5	0.8	11.3
GRAVEL (%)		0	0	0	0	0	0	0	0	0	0	0	0
SAND (%)		96.2	79.9	85.7	97.5	94.1	85.2	96.7	97.8	86.1	98.5	99.2	88.7
COARSE SAND (%)		0.1	0	0.1	0.1	0.1	0.2	0.2	0.3	0	0.1	0	0
MEDIUM SAND (%)		4	14.3	1.5	0.2	4.8	1.1	0.3	6.7	0.5	2.3	2.3	0.9
FINE SAND (%)		92.1	65.6	84.1	97.2	89.2	83.9	96.2	90.8	85.6	96.1	96.9	87.8
FINES (%)		3.8	20.1	14.3	2.5	5.9	14.8	3.3	2.2	13.9	1.5	0.8	11.3
D_{10} (μm)		95	93	82	89	84	81	88	87	81	90	87	82
D_{50} (μm)		179	167	115	157	136	112	156	153	111	167	156	115
D_{90} (μm)		357	618	187	221	309	168	230	360	161	310	278	182
(D_{90} / D_{10})		4	7	2	2	4	2	3	4	2	3	3	2
(D_{90} - D_{10}) (μm)		261	524	105	132	224	86	141	273	79	219	190	101
(D_{75} / D_{25})		2	2	2	2	2	1	2	2	1	2	2	2
(D_{75} - D_{25}) (μm)		103	194	49	63	84	46	69	103	44	101	94	50

backshore
shoreline
nearshore

Sediment Analysis - Beach 3

Sample ID		3-2-A	3-2-B	3-2-C	3-2-A	3-2-B	3-2-C	3-2-A	3-2-B	3-2-C	3-2-A	3-2-B	3-2-C
Sample Date		4/4/15	4/4/15	4/2/15	8/13/15	8/13/15	8/17/15	11/17/15	11/17/15	11/17/15	2/9/16	2/9/16	2/9/16
Grain Size (PCT_P and PCT)													
GS03 SIEVE 3" (75 MM)	75000	100	100	100	100	100	100	100	100	100	100	100	100
GS05 SIEVE 2" (50 MM)	50000	100	100	100	100	100	100	100	100	100	100	100	100
GS06 SIEVE 1.5" (37.5 MM)	37500	100	100	100	100	100	100	100	100	100	100	100	100
GS07 SIEVE 1" (25.0 MM)	25000	100	100	100	100	100	100	100	100	100	100	100	100
GS08 SIEVE 0.75" (19.0 MM)	19000	100	100	100	100	100	100	100	100	100	100	100	100
GS10 SIEVE 0.375" (9.5 MM)	9500	100	100	100	100	100	100	100	100	100	100	100	100
SIEVE NO. 004 (4.75 MM)	4750	100	100	100	100	100	100	100	100	100	100	100	100
SIEVE NO. 010 (2.00 MM)	2000	99	100	100	100	100	99.8	100	100	99.7	99.8	100	99.8
SIEVE NO. 020 (850 UM)	850	98.2	98.7	99.3	99.9	99.4	99.4	99.9	99.7	99.3	99.8	99.1	99.6
SIEVE NO. 040 (425 UM)	425	93.3	89.3	98.7	99.8	96.7	99	98.9	97.4	98.6	99.4	95.6	99.1
SIEVE NO. 060 (250 UM)	250	79.4	56.9	97	97.2	88.6	98.2	93.2	89	97.5	92	87.5	97.9
SIEVE NO. 080 (180 UM)	180	62.9	24	95.3	82.1	73	97.2	73.6	75.4	95.8	67.8	70.8	96.4
SIEVE NO. 100 (150 UM)	150	43.1	10.5	93.6	49.5	48.3	95.9	41.7	57.1	93.7	41.5	49.9	94.7
SIEVE NO. 200 (75 UM)	75	2.2	4.1	26.5	2	0.4	25.3	1.6	0.8	20.9	0.8	2.2	15.1
GRAVEL (%)		0	0	0	0	0	0	0	0	0	0	0	0
SAND (%)		97.8	95.9	73.5	98	99.6	74.7	98.4	99.2	79.1	99.2	97.8	84.9
COARSE SAND (%)		1	0	0	0	0	0.2	0	0	0.3	0.2	0	0.2
MEDIUM SAND (%)		5.7	10.7	1.3	0.2	3.3	0.8	1.1	2.6	1.1	0.4	4.4	0.7
FINE SAND (%)		91.1	85.2	72.2	97.8	96.3	73.7	97.3	96.6	77.7	98.6	93.4	84
FINES (%)		2.2	4.1	26.5	2	0.4	25.3	1.6	0.8	20.9	0.8	2.2	15.1
D_{10} (μm)		89	157	81	87	87	81	89	85	81	89	86	81
D_{50} (μm)		161	238	110	151	152	108	158	138	109	160	152	109
D_{90} (μm)		378	461	149	215	275	145	238	268	148	244	299	146
(D_{90} / D_{10})		4	3	2	2	3	2	3	3	2	3	3	2
(D_{90} - D_{10}) (μm)		289	305	68	128	188	64	149	183	67	155	212	65
(D_{75} / D_{25})		2	2	1	2	2	1	2	2	1	2	2	1
(D_{75} - D_{25}) (μm)		118	154	42	66	81	40	71	78	41	85	91	40

backshore
shoreline
nearshore

Sediment Analysis - Beach 4

Sample ID		4-2-A	4-2-B	4-2-C	4-2-A	4-2-B	4-2-C	4-2-A	4-2-B	4-2-C	4-2-A	4-2-B	4-2-C
Sample Date		4/4/15	4/4/15	5/18/15	8/12/15	8/12/15	8/17/15	11/11/15	11/11/15	11/11/15	2/9/16	2/9/16	2/9/16
Grain Size (PCT_P and PCT)													
GS03 SIEVE 3" (75 MM)	75000	100	100	100	100	100	100	100	100	100	100	100	100
GS05 SIEVE 2" (50 MM)	50000	100	100	100	100	100	100	100	100	100	100	100	100
GS06 SIEVE 1.5" (37.5 MM)	37500	100	100	100	100	100	100	100	100	100	100	100	100
GS07 SIEVE 1" (25.0 MM)	25000	100	100	100	100	100	100	100	100	100	100	100	100
GS08 SIEVE 0.75" (19.0 MM)	19000	100	100	100	100	100	85.1	100	100	100	100	100	100
GS10 SIEVE 0.375" (9.5 MM)	9500	100	100	100	100	93.1	77.3	100	100	100	100	100	100
SIEVE NO. 004 (4.75 MM)	4750	100	100	100	100	80.2	70.5	100	100	100	100	100	100
SIEVE NO. 010 (2.00 MM)	2000	99.6	97.8	100	99.8	65.3	66.7	99.5	100	100	100	99.6	98.8
SIEVE NO. 020 (850 UM)	850	98.7	93.8	99.6	99.3	46.4	61.3	98.9	98.6	99.4	99.8	96.7	96.1
SIEVE NO. 040 (425 UM)	425	96.2	86.5	99.4	96.2	24.3	54	93.4	94.5	97.4	98.1	88.3	92.3
SIEVE NO. 060 (250 UM)	250	77.1	79.1	97.7	83.2	14.9	46.6	70.7	87.4	91.7	87.4	78.4	87.5
SIEVE NO. 080 (180 UM)	180	39	66.5	92	50.1	8.5	37.2	32.2	71.6	73.7	49.2	62.3	75.4
SIEVE NO. 100 (150 UM)	150	17.4	39.5	77.3	21.8	4.6	26	12.8	46.3	45.3	22.3	39.4	55.6
SIEVE NO. 200 (75 UM)	75	4.5	2	6.6	1.8	2.4	0.5	1.6	0.1	1.5	2.7	3.2	4.5
GRAVEL (%)		0	0	0	0	19.8	29.5	0	0	0	0	0	0
SAND (%)		95.5	98	93.5	98.2	77.9	70	98.4	99.9	98.5	97.3	96.8	95.5
COARSE SAND (%)		0.4	2.2	0	0.2	14.9	3.8	0.5	0	0	0	0.4	1.2
MEDIUM SAND (%)		3.4	11.3	0.6	3.6	41	12.7	6.1	5.5	2.6	1.9	11.3	6.5
FINE SAND (%)		91.7	84.5	92.9	94.4	22	53.5	91.8	94.4	95.9	95.4	85.1	87.8
FINES (%)		4.5	2	6.6	1.8	2.3	0.5	1.6	0.1	1.5	2.7	3.2	4.5
D_{10} (μm)		125	90	82	105	217	98	138	87	88	106	90	85
D_{50} (μm)		202	162	119	181	1056	325	211	154	155	183	165	143
D_{90} (μm)		362	604	177	332	8147	20814	394	304	243	288	502	346
(D_{90} / D_{10})		3	7	2	3	38	212	3	3	3	3	6	4
(D_{90} - D_{10}) (μm)		237	514	95	227	7930	20715	256	217	155	182	412	261
(D_{75} / D_{25})		2	2	2	1	8	52	2	2	2	1	2	2
(D_{75} - D_{25}) (μm)		83	110	55	77	3177	7463	109	84	75	71	118	80

backshore
shoreline
nearshore

Sediment Analysis - Beach 5

Sample ID		5-7-A	5-7-B	5-7-C	5-7-A	5-7-B	5-7-C	5-7-A	5-7-B	5-7-C	5-7-A	5-7-B	5-7-C
Sample Date		4/1/15	4/1/15	4/2/15	8/12/15	8/12/15	8/18/15	11/13/15	11/13/15	11/13/15	2/11/16	2/11/16	2/11/16
Grain Size (PCT_P and PCT)													
GS03 SIEVE 3" (75 MM)	75000	100	100	100	100	100	100	100	100	100	100	100	100
GS05 SIEVE 2" (50 MM)	50000	100	100	100	100	100	100	100	100	100	100	100	100
GS06 SIEVE 1.5" (37.5 MM)	37500	100	100	100	100	100	100	100	100	100	100	100	100
GS07 SIEVE 1" (25.0 MM)	25000	100	100	100	100	100	100	100	100	100	100	100	100
GS08 SIEVE 0.75" (19.0 MM)	19000	100	100	100	100	100	100	100	100	100	100	100	100
GS10 SIEVE 0.375" (9.5 MM)	9500	100	100	100	100	100	100	100	100	100	100	100	100
SIEVE NO. 004 (4.75 MM)	4750	100	100	100	100	100	100	100	100	100	100	100	100
SIEVE NO. 010 (2.00 MM)	2000	100	100	99.9	100	99.8	99.2	100	100	99.4	100	100	97.4
SIEVE NO. 020 (850 UM)	850	99.9	99.9	97.3	100	98.3	96.6	100	99.6	96.2	100	99.8	95.3
SIEVE NO. 040 (425 UM)	425	99.3	94.3	75.8	99.7	84.6	79.9	99.8	94.4	80.4	99.2	94.2	78.6
SIEVE NO. 060 (250 UM)	250	72.8	40.7	43.9	84.9	50.9	48.6	82	62.5	50.5	66.6	59.8	46.7
SIEVE NO. 080 (180 UM)	180	26.8	16.4	23	31.8	21.3	30.6	31.3	33.6	25.2	26.4	29	24.4
SIEVE NO. 100 (150 UM)	150	8.9	7.6	12.2	9.8	7.4	19.3	9.8	17.1	12.5	9.5	13	13.7
SIEVE NO. 200 (75 UM)	75	3.6	1.6	3.5	1.9	0.4	1.4	0.6	-0.04	0.5	0.5	1.1	4.1
GRAVEL (%)		0	0	0	0	0	0	0	0	0	0	0	0
SAND (%)		96.5	98.4	96.5	98.1	99.6	98.6	99.4	100	99.5	99.5	99	95.9
COARSE SAND (%)		0	0	0.1	0	0.2	0.8	0	0	0.6	0	0	2.6
MEDIUM SAND (%)		0.7	5.7	24.1	0.3	15.2	19.3	0.2	5.6	19	0.8	5.8	18.8
FINE SAND (%)		95.8	92.7	72.3	97.8	84.2	78.5	99.2	94.4	79.9	98.7	93.2	74.5
FINES (%)		3.6	1.6	3.5	1.9	0.4	1.4	0.6	-0.04	0.5	0.5	1.1	4.1
D_{10} (μm)		157	162	152	152	156	110	151	112	133	152	133	150
D_{50} (μm)		215	276	285	203	248	259	204	217	249	219	227	273
D_{90} (μm)		355	408	679	302	560	650	318	395	649	366	399	694
(D_{90} / D_{10})		2	3	4	2	4	6	2	4	5	2	3	5
(D_{90} - D_{10}) (μm)		199	246	527	150	404	540	167	283	516	215	266	544
(D_{75} / D_{25})		1	2	2	1	2	2	1	2	2	2	2	2
(D_{75} - D_{25}) (μm)		85	147	232	64	178	226	68	144	207	109	144	217

backshore
shoreline
nearshore

Sediment Analysis - Beach 12

Sample ID		12-3-A	12-3-B	12-3-C	12-3-A	12-3-B	12-3-C	12-3-A	12-3-B	12-3-C	12-3-A	12-3-B	12-3-C
Sample Date		4/1/15	4/1/15	4/2/15	8/13/15	8/13/15	8/18/15	11/12/15	11/12/15	11/11/15	2/19/16	2/19/16	2/19/16
Grain Size (PCT_P and PCT)													
GS03 SIEVE 3" (75 MM)	75000	100	100	100	100	100	100	100	100	100	100	100	100
GS05 SIEVE 2" (50 MM)	50000	100	100	100	100	100	100	100	100	100	100	100	100
GS06 SIEVE 1.5" (37.5 MM)	37500	100	100	100	100	100	100	100	100	100	100	100	100
GS07 SIEVE 1" (25.0 MM)	25000	100	100	100	100	100	100	100	100	100	100	100	100
GS08 SIEVE 0.75" (19.0 MM)	19000	100	100	100	100	100	100	100	100	100	100	100	100
GS10 SIEVE 0.375" (9.5 MM)	9500	100	100	100	100	100	100	100	100	100	100	100	100
SIEVE NO. 004 (4.75 MM)	4750	100	100	100	100	100	100	100	100	100	100	100	100
SIEVE NO. 010 (2.00 MM)	2000	99.3	99.4	100	100	100	100	100	98.7	100	99.8	99.9	100
SIEVE NO. 020 (850 UM)	850	86.7	96.4	99.9	99.6	100	99.9	99.5	92.9	99.9	96.8	96.8	99.8
SIEVE NO. 040 (425 UM)	425	36.6	58	99.1	80	88.7	97.5	68.6	57.3	98.4	59.8	66.3	97.3
SIEVE NO. 060 (250 UM)	250	3.4	2.5	83.6	7.3	13.2	75.3	5.9	4.7	78.8	7.6	9.2	57.2
SIEVE NO. 080 (180 UM)	180	1.1	0.6	53.7	2.8	0.9	45.4	1.5	1.1	48.4	2.8	2.7	31.5
SIEVE NO. 100 (150 UM)	150	1	0.5	29.7	2.4	0.1	23.1	1.1	0.7	26.2	2.5	2.3	16.6
SIEVE NO. 200 (75 UM)	75	1	0.5	0.7	2.3	0.08	2.8	1	0.6	0.8	2.5	2	3
GRAVEL (%)		0	0	0	0	0	0	0	0	0	0	0	0
SAND (%)		99	99.5	99.3	97.7	99.9	97.2	99	99.4	99.2	97.5	98	97
COARSE SAND (%)		0.7	0.6	0	0	0	0	0	1.3	0	0.2	0.1	0
MEDIUM SAND (%)		62.7	41.4	0.9	20	11.3	2.5	31.4	41.4	1.6	40	33.6	2.7
FINE SAND (%)		35.6	57.5	98.4	77.7	88.6	94.7	67.6	56.7	97.6	57.3	64.3	94.3
FINES (%)		1	0.5	0.7	2.3	0.08	2.8	1	0.6	0.8	2.5	2	3
D_{10} (μm)		282	270	95	259	230	105	261	265	98	262	256	123
D_{50} (μm)		515	395	175	344	324	192	365	396	184	390	369	232
D_{90} (μm)		1071	758	312	610	461	358	688	804	339	752	732	387
(D_{90} / D_{10})		4	3	3	2	2	3	3	3	3	3	3	3
(D_{90} - D_{10}) (μm)		789	488	217	351	231	253	428	539	241	490	475	264
(D_{75} / D_{25})		2	2	2	1	1	2	2	2	2	2	2	2
(D_{75} - D_{25}) (μm)		368	268	92	123	114	97	198	293	93	268	230	149

backshore
shoreline
nearshore

Sediment Analysis - Beach 14

Sample ID		14-2-A	14-2-B	14-2-C	14-2-A	14-2-B	14-2-C	14-2-A	14-2-B	14-2-C	14-2-A	14-2-B	14-2-C
Sample Date		3/31/15	3/31/15	5/18/15	8/13/15	8/13/15	8/18/15	11/13/15	11/13/15	11/12/15	2/19/16	2/19/16	2/19/16
Grain Size (PCT_P and PCT)													
GS03 SIEVE 3" (75 MM)	75000	100	100	100	100	100	100	100	100	100	100	100	100
GS05 SIEVE 2" (50 MM)	50000	100	100	100	100	100	100	100	100	100	100	100	100
GS06 SIEVE 1.5" (37.5 MM)	37500	100	100	100	100	100	100	100	100	100	100	100	100
GS07 SIEVE 1" (25.0 MM)	25000	100	100	100	100	100	100	100	100	100	100	100	100
GS08 SIEVE 0.75" (19.0 MM)	19000	100	100	100	100	100	100	100	100	100	100	100	100
GS10 SIEVE 0.375" (9.5 MM)	9500	100	100	100	100	100	100	100	100	100	100	100	100
SIEVE NO. 004 (4.75 MM)	4750	100	100	100	99.9	100	100	100	99.6	100	100	100	100
SIEVE NO. 010 (2.00 MM)	2000	100	97.9	100	99	98.5	97.7	100	97.2	98.9	99.5	99.4	95.3
SIEVE NO. 020 (850 UM)	850	97	87.2	99.1	96.9	83.9	82.3	99	85	80.7	87	95.6	73.4
SIEVE NO. 040 (425 UM)	425	35.1	26.8	69.4	48.8	18.9	16.8	36	20.2	16.4	21.1	45.4	29.6
SIEVE NO. 060 (250 UM)	250	1.9	1.7	14.4	4.6	4.4	2.5	2.4	1.3	3.4	1.7	5.5	14.9
SIEVE NO. 080 (180 UM)	180	0.8	1.3	6.6	1.9	3.7	2.1	0.9	0.6	2	1.1	2.9	6.2
SIEVE NO. 100 (150 UM)	150	0.7	1.3	3	1.4	3.4	1.9	0.5	0.3	1.2	0.8	2.6	2.5
SIEVE NO. 200 (75 UM)	75	0.7	1.3	0.4	1.3	3.4	1.7	0.4	0.2	0.7	0.7	2.6	1.5
GRAVEL (%)		0	0	0	0.1	0	0	0	0.4	0	0	0	0
SAND (%)		99.3	98.7	99.6	98.6	96.6	98.3	99.6	99.4	99.3	99.3	97.4	98.5
COARSE SAND (%)		0	2.1	0	0.9	1.5	2.3	0	2.4	1.1	0.5	0.6	4.7
MEDIUM SAND (%)		64.9	71.1	30.6	50.2	79.6	80.9	64	77	82.5	78.4	54	65.7
FINE SAND (%)		34.4	25.5	69	47.5	15.5	15.1	35.6	20	15.7	20.4	42.8	28.1
FINES (%)		0.7	1.3	0.4	1.3	3.4	1.7	0.4	0.2	0.7	0.7	2.6	1.5
D_{10} (μm)		287	305	211	271	343	350	283	321	336	319	274	219
D_{50} (μm)		504	559	353	436	603	609	497	585	613	578	461	594
D_{90} (μm)		787	1074	688	771	1240	1316	770	1209	1320	1049	790	1635
(D_{90} / D_{10})		3	4	3	3	4	4	3	4	4	3	3	7
(D_{90} - D_{10}) (μm)		499	769	477	500	897	967	487	888	985	730	516	1417
(D_{75} / D_{25})		2	2	2	2	2	2	2	2	2	2	2	2
(D_{75} - D_{25}) (μm)		301	324	208	300	314	321	295	316	332	305	313	543

backshore
shoreline
nearshore

Sediment Analysis - Beach 22 (East)

Sample ID		22-2-A	22-2-B	22-2-C	22-2-A	22-2-B	22-2-C	22-2-A	22-2-B	22-2-C	22-2-A	22-2-B	22-2-C
Sample Date		4/3/15	4/3/15	4/2/15	8/11/15	8/11/15	8/18/15	11/10/15	11/10/15	11/18/15	2/17/16	2/17/16	2/17/16
Grain Size (PCT_P and PCT)													
GS03 SIEVE 3" (75 MM)	75000	100	100	100	100	100	100	100	100	100	100	100	100
GS05 SIEVE 2" (50 MM)	50000	100	100	100	100	100	100	100	100	100	100	100	100
GS06 SIEVE 1.5" (37.5 MM)	37500	100	100	100	100	100	100	100	100	100	100	100	100
GS07 SIEVE 1" (25.0 MM)	25000	100	100	100	100	100	100	100	100	100	100	100	100
GS08 SIEVE 0.75" (19.0 MM)	19000	100	100	100	100	100	100	100	100	100	100	100	100
GS10 SIEVE 0.375" (9.5 MM)	9500	100	100	100	100	97.5	100	100	100	100	100	100	100
SIEVE NO. 004 (4.75 MM)	4750	100	98.3	100	100	92	100	100	100	100	100	100	100
SIEVE NO. 010 (2.00 MM)	2000	99.6	83.5	99.6	99.7	75	99.6	99.5	99.5	100	99.7	96.5	100
SIEVE NO. 020 (850 UM)	850	96.9	55.9	94.1	99.1	40.7	96.5	97.7	98.8	99.2	97.4	85.9	98.8
SIEVE NO. 040 (425 UM)	425	87.1	37.2	48.2	97.8	22.2	71.5	87.8	96.6	91.6	88.4	69.5	62.3
SIEVE NO. 060 (250 UM)	250	45.7	22.9	6.1	80	14.4	22.7	45.1	78.9	58.6	42.9	42.2	6.8
SIEVE NO. 080 (180 UM)	180	9.9	10.7	2.7	22	6.6	8.1	9.3	32.3	25.1	7.6	15.9	3.8
SIEVE NO. 100 (150 UM)	150	2.9	5.5	2.3	5.3	3.1	4.3	1.3	10.4	10.9	1	5.7	3.4
SIEVE NO. 200 (75 UM)	75	1.8	3.6	2	1.4	2.2	2.4	0	1.3	0.5	0.1	2.9	3
GRAVEL (%)		0	1.7	0	0	8	0	0	0	0	0	0	0
SAND (%)		98.2	94.7	98	98.6	89.8	97.6	100	98.7	99.5	99.9	97.1	97
COARSE SAND (%)		0.4	14.8	0.4	0.3	17	0.4	0.5	0.5	0	0.3	3.5	0
MEDIUM SAND (%)		12.5	46.3	51.4	1.9	52.8	28.1	11.7	2.9	8.4	11.3	27	37.7
FINE SAND (%)		85.3	33.6	46.2	96.4	20	69.1	87.8	95.3	91.1	88.3	66.6	59.3
FINES (%)		1.8	3.6	2	1.4	2.2	2.4	-0.02	1.3	0.5	0.1	2.9	3
D_{10} (μm)		183	193	269	160	226	197	181	151	146	184	170	265
D_{50} (μm)		267	730	443	212	1102	341	266	205	230	272	299	383
D_{90} (μm)		528	2986	801	338	4339	715	496	350	415	481	1211	723
(D_{90} / D_{10})		3	15	3	2	19	4	3	2	3	3	7	3
(D_{90} - D_{10}) (μm)		346	2794	533	178	4113	517	315	199	269	297	1042	459
(D_{75} / D_{25})		2	5	2	1	4	2	2	1	2	2	3	2
(D_{75} - D_{25}) (μm)		157	1281	319	59	1555	215	155	73	146	152	346	245

backshore
shoreline
nearshore

Sediment Analysis - Beach 22 (West)

Sample ID		22-8-A	22-8-B	22-8-C	22-8-A	22-8-B	22-8-C	22-8-A	22-8-B	22-8-C	22-8-A	22-8-B	22-8-C
Sample Date		4/3/15	4/3/15	4/2/15	8/11/15	8/11/15	8/18/15	11/10/15	11/10/15	11/18/15	2/17/16	2/17/16	2/17/16
Grain Size (PCT_P and PCT)													
GS03 SIEVE 3" (75 MM)	75000	100	100	100	100	100	100	100	100	100	100	100	100
GS05 SIEVE 2" (50 MM)	50000	100	100	100	100	100	100	100	100	100	100	100	100
GS06 SIEVE 1.5" (37.5 MM)	37500	100	100	100	100	100	100	100	100	100	100	100	100
GS07 SIEVE 1" (25.0 MM)	25000	100	100	100	100	100	100	100	100	100	100	100	100
GS08 SIEVE 0.75" (19.0 MM)	19000	100	100	100	100	100	100	100	100	100	100	100	100
GS10 SIEVE 0.375" (9.5 MM)	9500	100	95.8	100	100	96.2	100	100	98.3	100	100	99.3	100
SIEVE NO. 004 (4.75 MM)	4750	100	93.7	100	100	94.7	100	100	93.7	100	100	94.9	100
SIEVE NO. 010 (2.00 MM)	2000	100	83.3	99.1	99.7	93.5	100	99.7	82.8	100	99.7	82.2	99.7
SIEVE NO. 020 (850 UM)	850	91.3	34.1	91.2	94.7	66.7	97.7	95.1	35.5	96.8	87.6	46.2	91
SIEVE NO. 040 (425 UM)	425	48.8	3.3	66.7	54.1	19.8	80.7	41.3	6.5	78.4	35.2	14.7	50.4
SIEVE NO. 060 (250 UM)	250	7.8	1.5	26.1	11.7	5.1	37.4	4.5	3	32.8	2.7	1.8	8.7
SIEVE NO. 080 (180 UM)	180	1.5	1.4	5.4	5.3	2.4	10.2	1.2	2	8	0.3	0.3	0.8
SIEVE NO. 100 (150 UM)	150	1.4	1.4	1.3	4.9	2.1	3.9	0.7	1.7	2.1	0.1	0.1	0.08
SIEVE NO. 200 (75 UM)	75	1.4	1.4	0.2	4.9	2.1	2.3	0.7	1.6	0.07	0.1	0.05	0
GRAVEL (%)		0	6.3	0	0	5.3	0	0	6.3	0	0	5.1	0
SAND (%)		98.6	92.3	99.8	95.1	92.6	97.7	99.3	92.1	99.9	99.9	94.9	100
COARSE SAND (%)		0	10.4	0.9	0.3	1.2	0	0.3	10.9	0	0.3	12.7	0.3
MEDIUM SAND (%)		51.2	80	32.4	45.6	73.7	19.3	58.4	76.3	21.6	64.5	67.5	49.3
FINE SAND (%)		47.4	1.9	66.5	49.2	17.7	78.4	40.6	4.9	78.3	35.1	14.7	50.4
FINES (%)		1.4	1.4	0.2	4.9	2.1	2.3	0.7	1.6	0.07	0.1	0.05	-0.04
D_{10} (μm)		261	508	194	259	319	184	273	478	185	282	351	254
D_{50} (μm)		438	1134	342	416	674	296	478	1121	306	517	931	423
D_{90} (μm)		834	3533	822	791	1801	627	797	3587	658	1008	3403	836
(D_{90} / D_{10})		3	7	4	3	6	3	3	7	4	4	10	3
(D_{90} - D_{10}) (μm)		573	3024	628	532	1481	443	524	3108	473	726	3052	581
(D_{75} / D_{25})		2	2	2	2	2	2	2	3	2	2	3	2
(D_{75} - D_{25}) (μm)		339	1033	292	311	657	179	319	1069	183	360	1152	339

backshore
shoreline
nearshore

Sediment Analysis - Beach 24

Sample ID		24-8-A	24-8-B	24-8-C	24-8-A	24-8-B	24-8-C	24-8-A	24-8-B	24-8-C	24-8-A	24-8-B	24-8-C
Sample Date		4/7/15	4/7/15	5/18/15	8/11/15	8/11/15	8/18/15	11/18/15	11/18/15	11/18/15	2/18/16	2/18/16	2/18/16
Grain Size (PCT_P and PCT)													
GS03 SIEVE 3" (75 MM)	75000	100	100	100	100	100	100	100	100	100	100	100	100
GS05 SIEVE 2" (50 MM)	50000	100	100	100	100	100	100	100	100	100	100	100	100
GS06 SIEVE 1.5" (37.5 MM)	37500	100	100	100	100	100	100	100	100	100	100	100	100
GS07 SIEVE 1" (25.0 MM)	25000	100	100	100	100	100	100	100	100	100	100	100	100
GS08 SIEVE 0.75" (19.0 MM)	19000	100	100	100	100	100	100	100	100	100	100	100	100
GS10 SIEVE 0.375" (9.5 MM)	9500	100	100	100	100	100	100	100	100	100	100	100	100
SIEVE NO. 004 (4.75 MM)	4750	100	100	100	100	100	100	100	100	100	100	100	100
SIEVE NO. 010 (2.00 MM)	2000	100	97.3	100	100	98.8	100	99.5	100	100	100	99.1	100
SIEVE NO. 020 (850 UM)	850	98.6	73.5	99.7	99.6	76.8	99.1	97.2	97.1	99.4	96.6	81.5	99
SIEVE NO. 040 (425 UM)	425	75	38.1	99.4	90.9	31.1	97.3	72.2	70.4	96.2	64.3	47.3	97.6
SIEVE NO. 060 (250 UM)	250	21.8	13.4	95.8	34	7.2	86.2	22.5	20.6	82.8	18.9	17.6	83
SIEVE NO. 080 (180 UM)	180	3.3	3.7	72.2	4.8	1.2	42.8	2.8	2.7	50.6	3.9	4.4	42.5
SIEVE NO. 100 (150 UM)	150	1.5	2.3	30.9	0.9	0.8	12.1	0.4	0.9	22.2	2.1	2.2	20.3
SIEVE NO. 200 (75 UM)	75	1.4	2.2	4.6	0.7	0.8	0.9	0.3	0.8	4.2	2	2.1	3.8
GRAVEL (%)		0	0	0	0	0	0	0	0	0	0	0	0
SAND (%)		98.6	97.8	95.4	99.3	99.2	99.1	99.7	99.2	95.8	98	97.9	96.2
COARSE SAND (%)		0	2.7	0	0	1.2	0	0.5	0	0	0	0.9	0
MEDIUM SAND (%)		25	59.2	0.6	9.1	67.7	2.7	27.3	29.6	3.8	35.7	51.8	2.4
FINE SAND (%)		73.6	35.9	94.8	90.2	30.3	96.4	71.9	69.6	92	62.3	45.2	93.8
FINES (%)		1.4	2.2	4.6	0.7	0.8	0.9	0.3	0.8	4.2	2	2.1	3.8
D_{10} (μm)		207	238	96	192	270	138	204	209	108	214	217	112
D_{50} (μm)		334	548	165	291	570	191	336	343	183	364	459	194
D_{90} (μm)		663	1551	232	422	1425	301	697	708	338	741	1298	327
(D_{90} / D_{10})		3	7	2	2	5	2	3	3	3	3	6	3
(D_{90} - D_{10}) (μm)		456	1312	136	230	1154	163	493	500	230	527	1081	215
(D_{75} / D_{25})		2	3	1	2	2	1	2	2	1	2	3	1
(D_{75} - D_{25}) (μm)		169	583	50	140	453	67	203	218	78	267	460	77

backshore
shoreline
nearshore

Sediment Analysis - Beach 1

Sample ID		1-5-A	1-5-B	1-5-C	1-5-A	1-5-B	1-5-C	1-5-A	1-5-B	1-5-C	1-5-A	1-5-B	1-5-C
Sample Date		4/6/15	4/6/15	4/2/15	8/12/15	8/12/15	8/17/15	11/10/15	11/10/15	11/17/15	2/12/16	2/12/16	2/12/16
Grain Size (PCT_P and PCT)													
GS03 SIEVE 3" (75 MM)	75000	100	100	100	100	100	100	100	100	100	100	100	100
GS05 SIEVE 2" (50 MM)	50000	100	100	100	100	100	100	100	100	100	100	100	100
GS06 SIEVE 1.5" (37.5 MM)	37500	100	100	100	100	100	100	100	100	100	100	100	100
GS07 SIEVE 1" (25.0 MM)	25000	100	100	100	100	100	100	100	100	100	100	100	100
GS08 SIEVE 0.75" (19.0 MM)	19000	100	100	100	100	100	100	100	100	100	100	100	100
GS10 SIEVE 0.375" (9.5 MM)	9500	100	100	100	100	100	100	100	100	100	100	100	100
SIEVE NO. 004 (4.75 MM)	4750	100	100	100	100	100	100	99.7	100	100	100	100	100
SIEVE NO. 010 (2.00 MM)	2000	100	99.7	99.7	100	97.9	99.5	99	100	100	100	100	100
SIEVE NO. 020 (850 UM)	850	95.2	97.1	99.2	100	84.7	98.7	95.7	99	98.7	99.4	99.1	99.9
SIEVE NO. 040 (425 UM)	425	87.3	64.8	96.5	99.4	52	93	53.7	72.3	90.8	81.6	85.7	97.8
SIEVE NO. 060 (250 UM)	250	80.7	21.3	76.8	73.4	21.2	66.7	12	20.2	62.4	34.3	46.4	82.5
SIEVE NO. 080 (180 UM)	180	61.1	10.4	38.2	21.9	7.4	31.9	4.3	6.4	27.9	9.4	18.3	48.5
SIEVE NO. 100 (150 UM)	150	34.7	6.9	18.2	6.3	3	14.3	3	3.4	10.8	2.6	7.2	25.6
SIEVE NO. 200 (75 UM)	75	9.5	6	2	2.2	1.7	2.1	2.7	2.6	0.5	0.8	1.8	0.8
GRAVEL (%)		0	0	0	0	0	0	0.3	0	0	0	0	0
SAND (%)		90.5	94.1	98	97.8	98.3	97.9	97	97.4	99.5	99.2	98.2	99.2
COARSE SAND (%)		0	0.3	0.3	0	2.1	0.5	0.7	0	0	0	0	0
MEDIUM SAND (%)		12.7	34.9	3.2	0.6	45.9	6.5	45.3	27.7	9.2	18.4	14.3	2.2
FINE SAND (%)		77.8	58.9	94.5	97.2	50.3	90.9	51	69.7	90.3	80.8	83.9	97
FINES (%)		9.5	6	2	2.2	1.7	2.1	2.7	2.6	0.5	0.8	1.8	0.8
D_{10} (μm)		96	209	114	160	199	131	251	207	147	183	161	99
D_{50} (μm)		**172**	368	201	217	**417**	216	**412**	343	**223**	299	**266**	**183**
D_{90} (μm)		585	739	359	352	1212	402	777	677	419	591	536	325
(D_{90} / D_{10})		6	4	3	2	6	3	3	3	3	3	3	3
(D_{90} - D_{10}) (μm)		489	530	245	192	1013	271	526	470	273	408	375	226
(D_{75} / D_{25})		2	2	2	1	3	2	2	2	2	2	2	2
(D_{75} - D_{25}) (μm)		97	270	85	76	425	128	308	196	142	173	172	83

backshore
shoreline
nearshore

Sediment Analysis - Beach 19

Sample ID		19-3-A	19-3-B	19-3-C	19-3-A	19-3-B	19-3-C	19-3-A	19-3-B	19-3-C	19-3-A	19-3-B	19-3-C
Sample Date		4/6/15	4/6/15	4/2/15	8/12/15	8/12/15	8/17/15	11/17/15	11/17/15	11/17/15	2/10/16	2/10/16	2/10/16
Grain Size (PCT_P and PCT)													
GS03 SIEVE 3" (75 MM)	75000	100	100	100	100	100	100	100	100	100	100	100	100
GS05 SIEVE 2" (50 MM)	50000	100	100	100	100	100	100	100	100	100	100	100	100
GS06 SIEVE 1.5" (37.5 MM)	37500	100	100	100	100	100	100	100	100	100	100	100	100
GS07 SIEVE 1" (25.0 MM)	25000	100	100	100	100	100	100	100	100	100	100	100	100
GS08 SIEVE 0.75" (19.0 MM)	19000	100	100	100	100	100	100	100	100	100	100	100	100
GS10 SIEVE 0.375" (9.5 MM)	9500	100	95.1	100	100	96.4	100	100	97.7	100	100	98	98
SIEVE NO. 004 (4.75 MM)	4750	100	93.9	100	100	95.1	98.2	100	93.2	100	100	94.8	93.8
SIEVE NO. 010 (2.00 MM)	2000	99.8	90.3	96.7	99.4	94.3	93.2	99.3	83.5	95.8	99.9	84.4	74.7
SIEVE NO. 020 (850 UM)	850	99.4	58.4	89.5	92.2	90.7	76.2	97.6	51.7	70.7	99.5	49.3	39.7
SIEVE NO. 040 (425 UM)	425	94.8	10.7	54.3	60.6	66.6	25.4	62.9	18.7	18.2	93.3	8.1	6.6
SIEVE NO. 060 (250 UM)	250	42.6	6	9.7	17.8	17.2	3	11.4	6.8	2.3	39.3	3.2	1.7
SIEVE NO. 080 (180 UM)	180	7.2	5.2	4	5.6	5.7	1.2	3.3	2.1	0.8	6.1	2.4	1.2
SIEVE NO. 100 (150 UM)	150	2.2	4.8	3	4.1	4.6	0.8	2.5	0.7	0.4	1.6	2.1	1
SIEVE NO. 200 (75 UM)	75	1.4	4.3	2.5	3.8	4.4	0.6	2.3	0	0.3	1	1.8	1
GRAVEL (%)		0	6.1	0	0	4.9	1.8	0	6.8	0	0	5.2	6.2
SAND (%)		98.6	89.6	97.6	96.2	90.7	97.6	97.7	93.2	99.7	99	93	92.8
COARSE SAND (%)		0.2	3.6	3.3	0.6	0.8	5	0.7	9.7	4.2	0.1	10.4	19.1
MEDIUM SAND (%)		5	79.6	42.4	38.8	27.7	67.8	36.4	64.8	77.6	6.6	76.3	68.1
FINE SAND (%)		93.4	6.4	51.9	56.8	62.2	24.8	60.6	18.7	17.9	92.3	6.3	5.6
FINES (%)		1.4	4.3	2.5	3.8	4.4	0.6	2.3	-0.003	0.3	1	1.8	1
D_{10} (μm)		187	445	258	222	228	299	252	288	326	189	451	465
D_{50} (μm)		271	776	410	382	364	597	377	820	648	279	884	1107
D_{90} (μm)		405	2063	929	817	844	1708	734	3571	1643	412	3235	4017
(D_{90} / D_{10})		2	5	4	4	4	6	3	12	5	2	7	9
(D_{90} - D_{10}) (μm)		218	1618	672	595	616	1409	482	3282	1317	223	2784	3552
(D_{75} / D_{25})		2	2	2	2	2	2	2	3	2	2	3	3
(D_{75} - D_{25}) (μm)		134	817	340	312	277	413	255	1106	520	137	1030	1416

backshore
shoreline
nearshore

Sediment Analysis - SWMU 4 (Southwest-Facing)

Sample ID		SWMU4-6-A	SWMU4-6-B	SWMU4-6-C	SWMU4-6-A	SWMU4-6-B	SWMU4-6-C	SWMU4-6-A	SWMU4-6-B	SWMU4-6-C	SWMU4-6-A	SWMU4-6-B	SWMU4-6-C
Sample Date		5/8/15	5/8/15	5/8/15	8/14/15	8/14/15	8/14/15	11/16/15	11/16/15	11/16/15	2/15/16	2/15/16	2/15/16
Grain Size (PCT_P and PCT)													
GS03 SIEVE 3" (75 MM)	75000	100	100	100	100	100	100	100	100	100	100	100	100
GS05 SIEVE 2" (50 MM)	50000	100	100	100	100	100	100	100	100	100	100	100	100
GS06 SIEVE 1.5" (37.5 MM)	37500	100	100	100	100	100	100	100	100	100	100	100	100
GS07 SIEVE 1" (25.0 MM)	25000	100	100	100	100	100	100	100	100	100	100	100	100
GS08 SIEVE 0.75" (19.0 MM)	19000	100	88.8	100	100	100	100	100	100	100	100	100	100
GS10 SIEVE 0.375" (9.5 MM)	9500	100	74.9	100	100	100	100	99.1	100	100	100	100	100
SIEVE NO. 004 (4.75 MM)	4750	100	41.6	100	100	99.3	100	94.9	86	100	100	100	100
SIEVE NO. 010 (2.00 MM)	2000	80.8	15.3	100	98.8	50.4	99.4	38.5	13.6	98.4	83	20.7	99.5
SIEVE NO. 020 (850 UM)	850	8.7	4	98	84.1	4.2	97.6	3.1	2.1	96	25.8	6.4	96.7
SIEVE NO. 040 (425 UM)	425	1	2.2	74.7	35.1	1.2	86.3	1.8	1.2	89.2	1.6	6	91.7
SIEVE NO. 060 (250 UM)	250	0.6	2	31.6	13	1	69.3	1.2	0.8	73.7	0.2	6	79.8
SIEVE NO. 080 (180 UM)	180	0.4	1.9	15.3	8.7	0.9	48.8	0.8	0.4	42.4	0.2	6	67.3
SIEVE NO. 100 (150 UM)	150	0.3	1.9	8.3	8.5	0.9	31.7	0.5	0.2	19.2	0.1	6	56.1
SIEVE NO. 200 (75 UM)	75	0.3	1.9	1.5	8.5	0.8	4.7	0.5	0.2	0.06	0.1	6	20.6
GRAVEL (%)		0	58.4	0	0	0.7	0	5.1	14	0	0	0	0
SAND (%)		99.8	39.7	98.5	91.5	98.5	95.3	94.4	85.8	99.9	99.9	94	79.4
COARSE SAND (%)		19.2	26.3	0	1.2	48.9	0.6	56.4	72.4	1.6	17	79.3	0.5
MEDIUM SAND (%)		79.8	13.1	25.3	63.7	49.2	13.1	36.7	12.4	9.2	81.5	14.7	7.8
FINE SAND (%)		0.7	0.3	73.2	26.6	0.4	81.6	1.3	1	89.1	1.4	0	71.1
FINES (%)		0.3	1.9	1.5	8.5	0.8	4.7	0.5	0.2	0.06	0.1	6	20.6
D_{10} (μm)		866	1524	162	280	959	96	1015	1551	108	542	1456	88
D_{50} (μm)		1390	5771	316	557	2000	191	2395	3093	195	1222	2845	161
D_{90} (μm)		3031	19658	673	1259	4035	549	4409	5796	461	2857	4287	447
(D_{90} / D_{10})		4	13	4	5	4	6	4	4	4	5	3	5
(D_{90} - D_{10}) (μm)		2165	18134	511	980	3076	453	3394	4245	354	2315	2831	359
(D_{75} / D_{25})		2	3	2	2	2	2	2	2	2	2	2	2
(D_{75} - D_{25}) (μm)		834	6893	210	381	1838	172	2051	1872	104	943	1474	143

backshore
shoreline
nearshore

Sediment Analysis - SWMU 4 (West-Facing)

Sample ID		SWMU4-17-A	SWMU4-17-B	SWMU4-17-C	SWMU4-17-A	SWMU4-17-B	SWMU4-17-C	SWMU4-17-A	SWMU4-17-B	SWMU4-17-C	SWMU4-17-A	SWMU4-17-B	SWMU4-17-C
Sample Date		5/8/15	5/8/15	5/18/15	8/14/15	8/14/15	8/14/15	11/16/15	11/16/15	11/16/15	2/15/16	2/15/16	2/15/16
Grain Size (PCT_P and PCT)													
GS03 SIEVE 3" (75 MM)	75000	100	100	100	100	100	100	100	100	100	100	100	100
GS05 SIEVE 2" (50 MM)	50000	100	100	100	100	100	100	100	100	100	100	100	100
GS06 SIEVE 1.5" (37.5 MM)	37500	100	100	100	100	100	100	100	100	100	100	100	100
GS07 SIEVE 1" (25.0 MM)	25000	100	100	100	100	100	100	100	100	100	100	100	100
GS08 SIEVE 0.75" (19.0 MM)	19000	100	100	100	100	100	100	100	100	100	100	100	100
GS10 SIEVE 0.375" (9.5 MM)	9500	100	100	100	100	100	100	100	100	100	100	100	100
SIEVE NO. 004 (4.75 MM)	4750	98.3	100	100	99.2	100	100	99.1	97.5	100	100	100	100
SIEVE NO. 010 (2.00 MM)	2000	79.6	95.1	88	58.4	93.9	99.6	78.3	63	100	100	92.9	100
SIEVE NO. 020 (850 UM)	850	24.7	42.2	73.8	8.8	26.6	98.5	22.3	10.1	99.7	77.8	22.6	97.4
SIEVE NO. 040 (425 UM)	425	1.3	5.8	59.2	1.7	1.2	96.9	2.6	6.3	98	3.9	1.6	96.5
SIEVE NO. 060 (250 UM)	250	1.3	5.8	49.3	1.6	1.1	94.2	1.5	5.1	96.6	3.9	1.6	95.2
SIEVE NO. 080 (180 UM)	180	1.3	5.8	42.3	1.6	1.1	90	1	4.4	94.8	3.8	1.6	92.7
SIEVE NO. 100 (150 UM)	150	1.3	5.8	37.1	1.6	1.1	84.9	0.7	4.1	93.1	3.8	1.6	89.7
SIEVE NO. 200 (75 UM)	75	1.3	5.8	13.2	1.6	1.1	35.7	0.7	3.2	82.6	3.8	1.6	64.9
GRAVEL (%)		1.7	0	0	0.8	0	0	0.9	2.5	0	0	0	0
SAND (%)		97	94.2	86.8	97.6	98.9	64.3	98.4	94.3	17.4	96.2	98.4	35.1
COARSE SAND (%)		18.7	4.9	12	40.8	6.1	0.4	20.8	34.5	0	0	7.1	0
MEDIUM SAND (%)		78.3	89.3	28.8	56.7	92.7	2.7	75.7	56.7	2	96.1	91.3	3.5
FINE SAND (%)		0	0	46	0.07	0.1	61.2	1.9	3.1	15.4	0.1	0.04	31.6
FINES (%)		1.3	5.8	13.2	1.6	1.1	35.7	0.7	3.2	82.6	3.8	1.6	64.9
D_{10} (μm)		569	509	96	890	555	82	564	889	84	465	588	83
D_{50} (μm)		1274	1011	260	1754	1153	92	1305	1663		667	1198	
D_{90} (μm)		3255	1859	2541	3922	1906	238	3263	3967	473	1380	1934	423
(D_{90} / D_{10})		6	4	26	4	3	3	6	4	6	3	3	5
(D_{90} - D_{10}) (μm)		2686	1350	2444	3032	1351	156	2699	3078	388	916	1346	341
(D_{75} / D_{25})		2	2	8	2	2	2	2	2	2	2	2	2
(D_{75} - D_{25}) (μm)		1004	814	974	1720	746	54	1014	1632	110	303	728	69

backshore
shoreline
nearshore

Figures

Figure E-1. Transects, shoreline, and locations of sediment samples at Beach 2 in April 2015.

Figure E-2. Transects, shoreline, and locations of sediment samples at Beach 3 in April 2015.

Figure E-3. Transects, shoreline, and locations of sediment samples at Beach 4 in April 2015.

Figure E-4. Transects, shoreline, and locations of sediment samples at Beach 5 in April 2015.

Figure E-5. Transects, shoreline, and locations of sediment samples at Beach 12 in April 2015.

Figure E-6. Transects, shoreline, and locations of sediment samples at Beach 14 in April 2015.

Figure E-7. Transects, shoreline, and locations of sediment samples at Beach 22 (east) in April 2015.

Figure E-8. Transects, shoreline, and locations of sediment samples at Beach 22 (west) in April 2015.

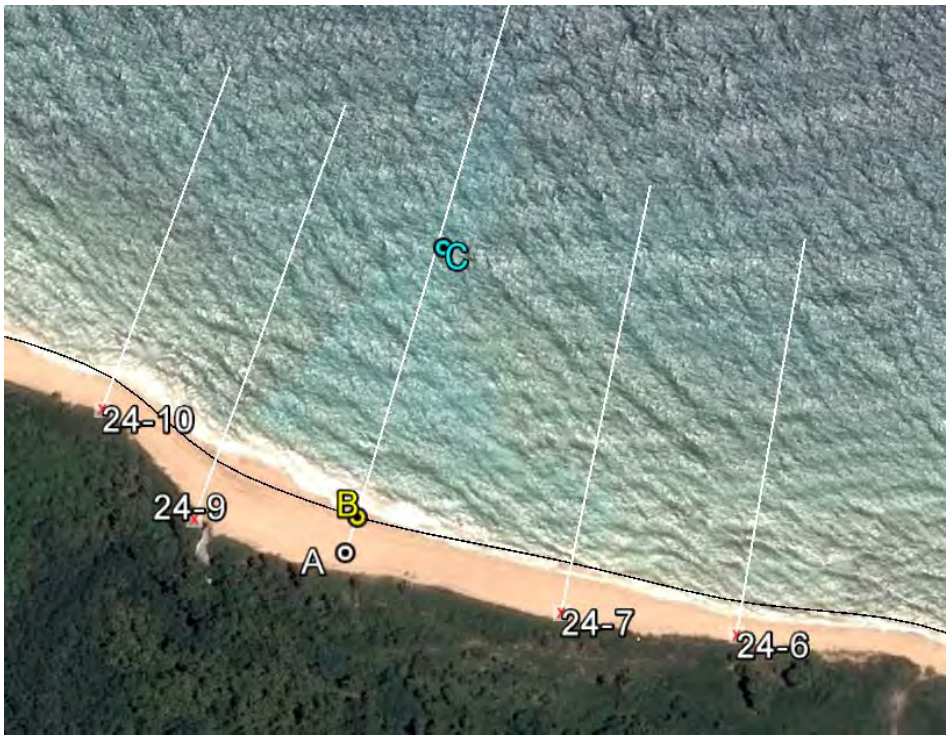


Figure E-9. Transects, shoreline, and locations of sediment samples at Beach 24 in April 2015.

Figure E-10. Transects, shoreline, and locations of sediment samples at Beach 1 in April 2015.

Figure E-11. Transects, shoreline, and locations of sediment samples at Beach 19 in April 2015.

Figure E-12. Transects, shoreline, and locations of sediment samples at SWMU 4 (south) in May 2015.

Figure E-13. Transects, shoreline, and locations of sediment samples at SWMU 4 (west) in May 2015.

Appendix F
Munitions Surrogate Surveys

APPENDIX F

Munitions Surrogate Surveys

1. Fabrication

Inert munitions surrogates were fabricated out of aluminum by computer numerical control (CNC) machining to replicate the geometry of the actual munitions and explosives of concern (MEC) type selected. The surrogates included metals of heavier densities (e.g., steel and lead) to achieve the required weights and location of the center of gravity (CG). Fabrication focused on achieving dimensions, shape, weight, location of CG, and arrangement and size of fins where applicable. Surface finish and details such as cavities, protrusions, lifting eyes, small/flexible fins, and similar small features were not replicated. All surrogates were of rugged construction to withstand corrosion and being submerged in sea water and on sandy/rocky sea bottoms for an extended period of time. Each surrogate was fitted with a battery-powered Sonotronics acoustic transmitter on the forward end (tip) in a manner such that the acoustic signal emitted by the transmitter was not shielded by the surrogate, and it did not excessively protrude to avoid damage or accidental detachment.

Same-type surrogates were painted with the same marine grade bright, neon-like color paint to allow for easy visual identification underwater. Using marine grade epoxy black paint, the surrogates were labeled "INERT/INERTE" to indicate the surrogates were not live, with the acoustic transmitter identification (tag) number, and an identification (ID) code to assist with the visual identification underwater. In addition, these labels were scribed on the surrogate surface in case the painted labels faded. The acoustic transmitter tag number identified the transmitter's frequency of transmission and the pattern of the acoustic signal transmitted (code). The surrogate ID codes consisted of numbers/letters representing:

- Beach where the surrogate was deployed
- MEC type surrogate
- Surrogate number
- Total number of surrogates deployed at that beach

For example, 1-MK76-3/4 identified the surrogate deployed at Beach 1, as an MK 76 bomb surrogate, and the third surrogate of the four deployed at that beach.

Prior to deployment, several surrogates of each type underwent quality control inspection at Camp Garcia. The dimensions, weights, locations of CG, surrogate ID labeling, and color scheme used were verified, as well as the proper operation of acoustic transmitters.

Table F-1 lists MEC surrogate types, quantities, colors, and acoustic transmitter. **Figure F-1** to **Figure F-7** show examples of each MEC surrogate type.

Table F-1. MEC surrogate quantities, color and acoustic transmitter model

Type	Quantity	Color	Acoustic Transmitter
5-inch 38 Caliber Projectile	15*	Orange	EMT-01-2
2.75-inch Rocket	16	Red	EMT-01-2
MK 82 Bomb	7	Magenta	EMT-01-2
MK 118 Submunition	2	Yellow with black stripes	EMT-01-2
81-mm Mortar	12	Green	IBT-96-9-E
MK 76 Practice Bomb	9	Violet	EMT-01-2

* 8 surrogates were fabricated and 7 were refurbished from a previous Department of Defense (DOD) experiment
Acoustic transmitters by Sonotronics, Inc.

m = millimeter

2. Deployment

2.1 Locations

Figure F-8 through **Figure F-13** show the surrogate deployment locations and depth contours (m, PRVD02) for Live Impact Area (LIA) UXO 2 Beaches 2, 3, 4, 5, and 14; **Figure F-14** through **Figure F-16** for Eastern Maneuver Area (EMA) and Surface Impact Area (SIA) Beaches 22 and 24; and **Figure F-17** and **Figure F-18** for South SIA UXO 8 Beaches 1 and 19. Surrogates at the same locations were not deployed bundled, but a few meters apart from each other to avoid interfering.

2.2 Methodology

Prior to deployment, a Dive Safety Plan (DSP) was developed in accordance with the requirements set forth by the Navy and in the CH2M HILL AAUS Dive Safety Manual and the CH2M HILL Commercial/Munitions Diving Safe Practices Manual. The MEC surrogates were deployed by a team consisting of munitions, science, and commercial divers and field support staff between March 25 and April 1, 2015.

The team on-board deployment and survey boats navigated to the selected locations. At each beach and surrogate location, munitions divers surveyed the deployment area with a magnetometer to ensure the area was clear of MEC and magnetic anomalies, and safe for anchoring and surrogate deployment. Following the munitions divers' survey, science divers conducted biological surveys to ensure that no sensitive, threatened, or endangered species or habitats would be affected during the deployment of the surrogates, and that the surrogates would not be deployed in holes or heavily vegetated areas, on or close to reefs and rock outcrops. Upon confirmation that the deployment location was adequate, commercial divers carried and deployed the surrogates by hand or with the aid of lift bags. Surrogates that could be handled underwater were hand-carried and deployed gently, flat on the sea bottom. Heavy surrogates, like the 530-pound (lb) MK 82s, were deployed using lift bags, where the divers guided the surrogate down through the water column to rest on the sea bottom as air was slowly let out of the lift bag. **Figure F-19** shows a munitions diver performing an MEC avoidance survey, **Figure F-20** shows an example of a surrogate deployed on the sea bottom, and **Figure F-21** an example of a heavy MK 82 surrogate being deployed with a lift bag.

3. Surveys (Tracking)

3.1 Equipment

Surveys were performed by the boat crew using the same equipment used for the beach surveys. This included the survey boat, the boat Real Time Kinetic (RTK) global positioning system (GPS) rover receiver, single-beam echo sounder, laptop computer, and the HYPACK hydrographic software for navigation and data acquisition.

Surrogates were searched and identified from the survey boat by their acoustic signature and visually. The Sonotronics manual tracking kit (MANTRAK) was used to search and identify surrogates by acoustic signal frequency and code, and a bathyscope for visual search and identification by surrogate shape, color, and label on the equipment. This equipment is shown in **Figure F-22**. On occasions, an underwater diver receiver (UDR), similar to the MANTRAK, was used and operated from the survey boat side.

Technical specifications of the Sonotronics acoustic transmitters, MANTRAK kit, and UDR are included as an attachment to this Appendix.

3.2 Procedure

The surveys were performed according to the following procedure:

1. Boat crew navigated to the last known location of the MEC surrogate to be surveyed and using the hydrophone and bathyscope searched and identified the surrogate.
2. If the MEC surrogate acoustic signal was detected or the surrogate was found visually, the boat crew marked the location with a small float.
3. The boat crew recorded in field notebook:
   - date and time
   - wind speed and direction
   - wave height, period, and direction
   - location (easting and northing, Universal Transverse Mercator [UTM] 20 N NAVD83)
   - water depth (meters [m], Puerto Rico Vertical Datum 2002 [PRVD02])
   - acoustic transmitter signal detected or not
   - surrogate visually located or not
   - depth of burial (fully buried or as a percentage of surrogate diameter)
   - heading (surrogate tip pointing to)
   - sea bottom conditions
   - comments
4. If the MEC surrogate acoustic signal was not detected and the surrogate was not found visually, this was noted and the last known location was recorded in the field notebook.
5. Boat crew took a photograph of the surrogate, when possible.
6. Boat crew navigated to the next MEC surrogate location and surveyed following the steps listed.

3.3 Survey Dates

A total of 19 surveys were performed from April 2015 to December 2016. **Table F-2** lists the dates of the MEC surrogate surveys for each beach.

Table F-2. MEC Surrogate Survey Dates

Survey	Beach								
	1	**2**	**3**	**4**	**5**	**14**	**19**	**22**	**24**
2015									
1 †	3/28	3/26-27	3/27	3/27	3/25-26	3/31-5/14	3/28	3/25	3/31-4/1
2	*	*	*	*	*	*	*	*	*
3	*	*	*	*	*	*	*	*	*
4	7/9	7/9	7/9	7/8	7/13	7/24	*	7/10	7/10
5	8/20	8/20	8/20	8/20	8/19	8/19	8/20	8/19	8/19
6	9/23	9/22	9/22	9/22	9/23	9/18	9/23	9/18	9/18
7	10/16	10/13	10/13	10/13	10/14	10/19	10/13	10/14	10/15
8	11/17	11/17	11/17	11/11	11/13	11/12	11/17	11/18	11/18
9	12/16	12/14	12/14	12/14	12/11	12/10	12/10	12/8	12/9
2016									
10	1/21	1/6-16	1/6	1/6	1/22	1/22	1/21	1/20	1/22
11	2/12	2/9	2/9	2/10	2/11	2/19	2/10	2/17	2/18
12	3/8	3/9	3/9	3/9	3/15	3/16	3/18	3/14	3/15
13	4/13	4/8	4/8	4/8	4/13	4/6	4/7	4/13	4/6
14	5/5	5/5	5/5	5/5	5/5	5/4	5/6	5/3	5/3
15	6/9	6/7	6/7	6/7	6/8	6/8	6/9	6/6	6/6
16	7/20	7/20	7/15	7/15	7/18	7/18	7/20	7/14	7/14
17	8/9	8/8	8/8	8/8	8/10	8/10	8/9	8/11	8/11
18	9/21	9/20	9/20	9/19	9/15	9/15-17	9/19	9/18	9/17
19	10/6	10/6	10/6	10/3	*	*	10/6	10/5	10/5
20	11/8	11/8	11/8	11/11	11/15	11/11	11/11	11/7	11/7
21	12/6	12/6	12/6	12/6	12/7	12/7	12/8	12/7	12/9

† Deployment

* Survey not performed due to adverse weather conditions, logistics, or activities in demo/burn exclusion zones.

4. Maintenance

While the surrogates did not require maintenance, due to their rugged construction to withstand corrosion and being submerged in sea water for a long time, the acoustic transmitters had integrated batteries with a life of approximately 24 months. This required the replacement of the transmitters in mid-2016 to allow for the continued location and identification of the surrogates. A team of munitions, scientific, commercial divers, and field support staff was mobilized to perform the in situ replacement of the acoustic transmitters. The safety procedures used for the deployment of the surrogates was followed. Ten of the 61 transmitters were replaced on

unburied surrogates in June and July 2016. The replacement of the remaining 51 transmitters was planned for September of 2016. However, only 37 transmitters were replaced at that time, since 10 were buried too deep and 4 were not found. All surrogates were minimally or not disturbed during the acoustic transmitter replacement and were left in the same condition as found.

5. Diver Surveys

The replacement of the acoustic transmitters in June and July 2016, provided an opportunity to assess in detail the condition of the surrogates in terms of location, water depth, burial depth, orientation, and bottom conditions. The team performed the following tasks:

1. Recorded date, time, and field staff
2. Recorded weather conditions
3. Verified the functionality and characteristics of the new transmitters
4. Located, identified, and documented surrogate locations
5. Conducted MEC avoidance surveys
6. Surveyed areas around surrogates to identify and locate any sensitive, threatened, and/or endangered species and habitats that could be affected by the field activities
7. Unburied surrogates (where needed)
8. Measured depth of burial and assessed surrogate and bottom conditions
9. Took photographs and video
10. Replaced the surrogate transmitters
11. Reburied the surrogates (where needed)
12. Documented surrogate and bottom conditions

Of the 61 surrogates, the depth of burial of 33 surrogates was measured using a U frame and tape measure as shown in **Figure F-23**. For 14 surrogates, the burial depth was estimated from underwater photos. For 10 surrogates that were buried too deep the depth of burial was estimated by the divers. Four surrogates were not found.

6. Surrogate Recovery

In June 2017, a team consisting of munitions, science, commercial divers, and field support staff was mobilized to recover the MEC surrogates. The recovery was performed between June 29 and July 11, 2017. Of the 61 surrogates originally deployed in March/April 2015:

- 1 was found on land near the boat ramp at Beach 5 in March 2017 (the 2.75-inch rocket surrogate, 5-275-2/4, was assumed to have been removed by an intruder)
- 52 were recovered
- 8 were lost
  - 1 at Beach 14 (14-MK118-2/2)
  - 5 at Beach 22 (22-81-2/5, 22-81-4/5, 22-MK76-2/5, 22-MK76-4/5 and 22-MK76-5/5)
  - 2 at Beach 24 (24-275-1/4 and 24-275-4/4)

The procedure followed to recover the surrogates was similar to that employed for the deployment and the replacement of the acoustic transmitters. The team navigated to the selected locations, and at each location munitions divers surveyed the area with a magnetometer to ensure the area was clear of MEC and magnetic

anomalies, and safe for anchoring and surrogate recovery. Following the munitions divers' survey, science divers conducted biological surveys to ensure that no sensitive, threatened, or endangered species or habitats would be affected by the recovery. Upon confirmation that the recovery could proceed, commercial divers recovered the surrogates by hand or with the aid of lift bags.

In addition, the team recorded the following:

1. Date, time, and field staff
2. Weather conditions
3. Surrogate location and water depth
4. Surrogate depth of burial, orientation, and bottom type
5. Took photographs and video

Attachment

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EMT Equipment Marker Transmitters

EMT-01 series: Durable, low cost, equipment marker pingers. Lifetime: to 48 months; Range: to 4km. PVC packaging provides excellent depth ratings and durability.

EMT-01-1: Long life 48 month medium power transmitter

Length: 99mm
Diameter: 19mm
Weight (in air): 48g
Weight (in water): 18g
Lifetime: 48 month (Deactivated via magnet switch.)
Range: Up to 1km
Depth rating: 2500m

EMT-01-2: High power 18 month transmitter

Length: 99mm
Diameter: 19mm
Weight (in air): 48g
Weight (in water): 18g
Lifetime: 18 month (Deactivated via magnet switch.)
Range: Up to 3km
Depth rating: 2500m

EMT-01-3: Highest power, User Replaceable Batteries.

Length: 201mm
Diameter: 32mm
Weight (in air): 252g
Weight (in water): 90g
Mounting Hole Size: 3/16"
Range: Up to 4km
Lifetime: 6 months
Depth rating: 1km
Batteries: 2xAA 3.6v: 161.5dB (ref 1uPascal @ 1m)
(Pinger is deactivated by removing the batteries.)
Immersion Activation Option available. Add ordering code –IA: EMT-01-3-IA

***Ping rates, ping widths, and ping patterns may be specified when ordering for any pinger.**

Standard Operating Frequencies:
(in 1kHz increments)

EMT-01-1: 69kHz—83kHz
EMT-01-2: 69kHz—83kHz
EMT-01-3: 30kHz—40kHz

Updated: 8/14/2009

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EMT Equipment Marker Transmitters
Options

EMT telemetry pingers produce two separate sets of intervals (time between pings). One interval set is for unique identification of the pinger (fixed), and the other represents the variable telemetry data. The total time between successive angle measurements is approximately 30 seconds. The USR-96 and DH-4 hydrophone from a MANTRAK kit is used to receive data telemetered from the EMTs. The USR-96 alternately displays the ACT ID of the pinger, and selected telemetry on its integral LCD.

EMT-AR Tilt Sensing

EMT-AR pingers sense tilt angles relative to gravity with a 5º resolution, and a +/- 2.5º accuracy for tilt angles between 15 and 90 degrees, and +/- 5º accuracy for tilt angles between 0 and 12.5 degrees. Alternatively, the EMT-AR may be ordered to provide a unique alarm pattern if a tilt angle exceeds a preselected amount.

EMT-TT Temperature Sensing

EMT-TT pingers sense ambient temperature between –5ºC and +40ºC with a factory standard accuracy of +/-2º C, and a resolution of .5º C. Greater accuracies may be obtained by calibrating the transmitter in fixed temperature solutions

Model	Lifetime	Range	Depth rating	Length	Diameter	Weight
EMT-AR-1	48 months	1km+	2.5km+	99mm	19mm	48g
EMT-AR-2	18 months	3km+	2.5km+	99mm	19mm	48g
EMT-AR-3	To 6 mo*	To 4km+*	1km	201mm	32mm	252g
EMT-TT-1	48 months	1km+	2.5km+	99mm	19mm	48g
EMT-TT-2	18 months	3km+	2.5km+	99mm	19mm	48g
EMT-TT-3	To 6 mo*	To 4km+*	1km	201mm	32mm	252g

* parameters dependant on battery selection

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Active Tracking

- ART Acoustic and Radio Transmitter
- CHP Transmitters
- CT Coded Transmitters
- CTT Temperature Transmitter
- CUB Cellular Uplink Buoy
- DT Depth Transmitters
- Home
- IBT Series Miniature Transmitters
- MANTRAK Kit Surface Receiver
- Miniature Transmitters
- DH-4 Hydrophones
- TH-2 Hydrophones
- Prices
- PT Series Subminiature Transmitters
- Telemetry Transmitters
- UDR Underwater Diver Receiver
- USR-08 Ultrasonic Receiver

Passive Tracking

- ART Acoustic and Radio Transmitter
- AT Accelerometer Based Acoustic Transmitter
- CHP Transmitters
- CT Coded Transmitters
- CUB Cellular Uplink Buoy
- DT Depth Transmitters
- Home
- IBT Series Miniature Transmitters
- Miniature Transmitters
- miniSUR
- DH-4 Hydrophones
- TH-2 Hydrophones
- Prices
- PT Series Subminiature Transmitters
- SUR Submersible Ultrasonic Receiver
- Telemetry Transmitters

Equipment Tracking

- AT Accelerometer Based Acoustic

Miniature Transmitters

Pico Transmitters

Pico with Penny

IBT-96-9

The Itty-Bitty Transmitter family represents a combination of very small size and long life acoustic transmitters. Beginning at .7g in weight in water, these small transmitters allow researchers unique choices for tagging slender fishes, while the long life, continuous transmissions allow active tracking for an entire year.

IBT Tags (miniature)

MODEL[3]	Length	OD	WT in H_20	Range[1]	Autonomy[2]
IBT-96-1	25mm	8mm	1.5g	500m+	21 days
IBT-96-2	28mm	9.5mm	2.5g	500m+	60 days
IBT-96-5	36mm	13mm	3.2g	500m+	21 days
IBT-96-9-I	47mm	10.5mm	3.8g	750m+	9+ months
IBT-96-9-E	50mm	10.5mm	5g	750m+	9+ months

The Pico Tag family represents the smallest acoustic transmitters in the Sonotronics product line. Beginning at .6g in weight in water, these tiny transmitters will allow researchers to gain valuable information on small species never possible before. The PicoTags come standard in bullet shaped packaged shown in the photo. This packaging is more commonly used for internal implant or in cases where gluing the transmitter is appropriate.

PicoTags (sub-miniature)

MODEL	Length	OD	WT in H_20	Range[1]	Autonomy[2]
PT-1	16mm	7.1mm	.7g	500m+	7 days
PT-2	19mm	7.1mm	1g	500m+	12 days
PT-3	19mm	7.8mm	1g	500m+	21 days
PT-4	25mm	9.0mm	2.3g	750m+	90 days

Notes

1. Range is typical under good conditions, using a Sonotronics active receiver and directional

Transmitter
EMT-AR Accelerometer Based Acoustic Transmitter
EMT Equipment Marking Transmitters
Home
MANTRAK Kit Surface Receiver
DH-4 Hydrophones
TH-2 Hydrophones
Prices
Telemetry Transmitters
Tilt-Angle Sensing Transmitters
UDR Underwater Diver Receiver

hydrophone.

2. Autonomy based on a ping rate of once per second. Extened lifetimes are available by cycling the transmitters, please contact Sonotronics for more details
3. -E is the extension denoting external mount, -I denotes internal implant. Please specify internal or external when ordering transmitters.

Links:
No Product Downloads
See YouTube Videos in our Resources Section

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Suffusion theme by Sayontan Sinha

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MANTRAK kit

The MANTRAK kit contains all of the basic tools necessary for locating pingers from a surface vessel: deck receiver, hydrophone, and useful accessories, housed in a rugged Pelican case.

The MANTRAK kit includes:

- **USR-08 Receiver**
- **DH-4 Directional Hydrophone**
- **Test Transmitter**
- **Waterproof Pelican Case**
- **External Speaker**
- **High Quality Koss headphones**
- **Extra Battery Pack**
- **Auto Power Battery Cable**

Description of the tools:

USR-08 receiver: A narrow band scanning receiver, and is the superior choice for range and unique identification of individual transmitters. Transmissions from pingers are presented as an audio output and details displayed on the integral LCD. Several modes are available from detecting simple pingers, to decoding and displaying ACT coded transmissions and associated telemetry as well as R-code IDs.

DH-4 hydrophone: A directional hydrophone designed to maximize range and provide directivity for locating transmitters.

Other Accessories: A test transmitter included in the kit allows the user to test the equipment and the environment to determine expected range. The headphones and speaker allow for different methods of listening for transmitters. The auto power battery cable allows for the USR-08 to be powered and charged by a 'cigarette plug' outlet, while the extra battery pack allows for longer use when internal power is used.

Options: The USR-08 is available with optional dual hydrophone support, as well as logging and Bluetooth or RS-232 connectivity. Additionally, external GPS support is available via an auxiliary serial port. A TH-2 towed hydrophone may be added to aid in active tracking at trolling speeds.

Updated: 8/25/2009

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UDR_II Underwater Diver Receiver

The Sonotronics Underwater Diver Receiver (UDR) allows a diver to locate and approach any object in a marine environment previously marked with a Sonotronics equipment marker transmitter (EMT), as well as other manufacturers' compatible pingers. These objects include submersibles, water monitoring equipment, divers, or virtually any other underwater object. Applications include military, ocean oil drilling operations, surveying, and fisheries..

Features

- The UDR_II is an easy to use unit allowing precise relocation of any object marked with an ultrasonic pinger. The UDR has a wide range of gain possible so objects far away can be detected, while precise positioning can be obtained in the immediate area, even under low visibility conditions.
- Underwater headphones are available as standard accessory, however optional Bonephones are available for diving with a hood or when headphones are not desired.
- The UDR_II has Pulse Interval Display capability, allowing detection of telemetry and ID intervals by the receiver, allowing discrimination of specific targets in environments containing large numbers of pingers.
- The UDR_II displays bars proportional to the strength of the incoming signal. This visual cue makes approaching pingers even easier..

Specifications:

Dimensions:	Length: (From Display to outer rim) 16cm
	Width: (At outer rim) 11cm
	Height: (Bottom of Handle to top of unit) 20cm
Weight (Air):	UDR: 900g, Headphones: 415g
Sensitivity:	20uV, (S+N)/N = 30dB
Frequencies:	30 to 90 kHz
Controls:	Gain, volume, frequency
Autonomy:	8 hours on fresh battery charge
Depth Rating:	100m

**User can preprogram the unit before the dive for a variety of different applications.

NEW: Modular 'Front End'

The NEW UDR_II allows connection to a variety of hydrophones, allowing use by both diver AND deck personnel.

Updated: 3/6/2008

3169 S. Chrysler Ave. Tucson, AZ U.S.A. phone: (520) 746-3322 fax: (520) 294-2040

Figures

Figure F-1. 5-inch 38 caliber projectile surrogate (fabricated).

Figure F-2. 5-inch 38 caliber projectile surrogate (refurbished).

Figure F-3. 2.75-inch rocket surrogate.

Figure F-4. MK 82 bomb.

Figure F-5. MK 118 submunition surrogate.

Figure F-6. 81-mm mortar surrogate.

Figure F-7. MK 76 practice bomb surrogate.

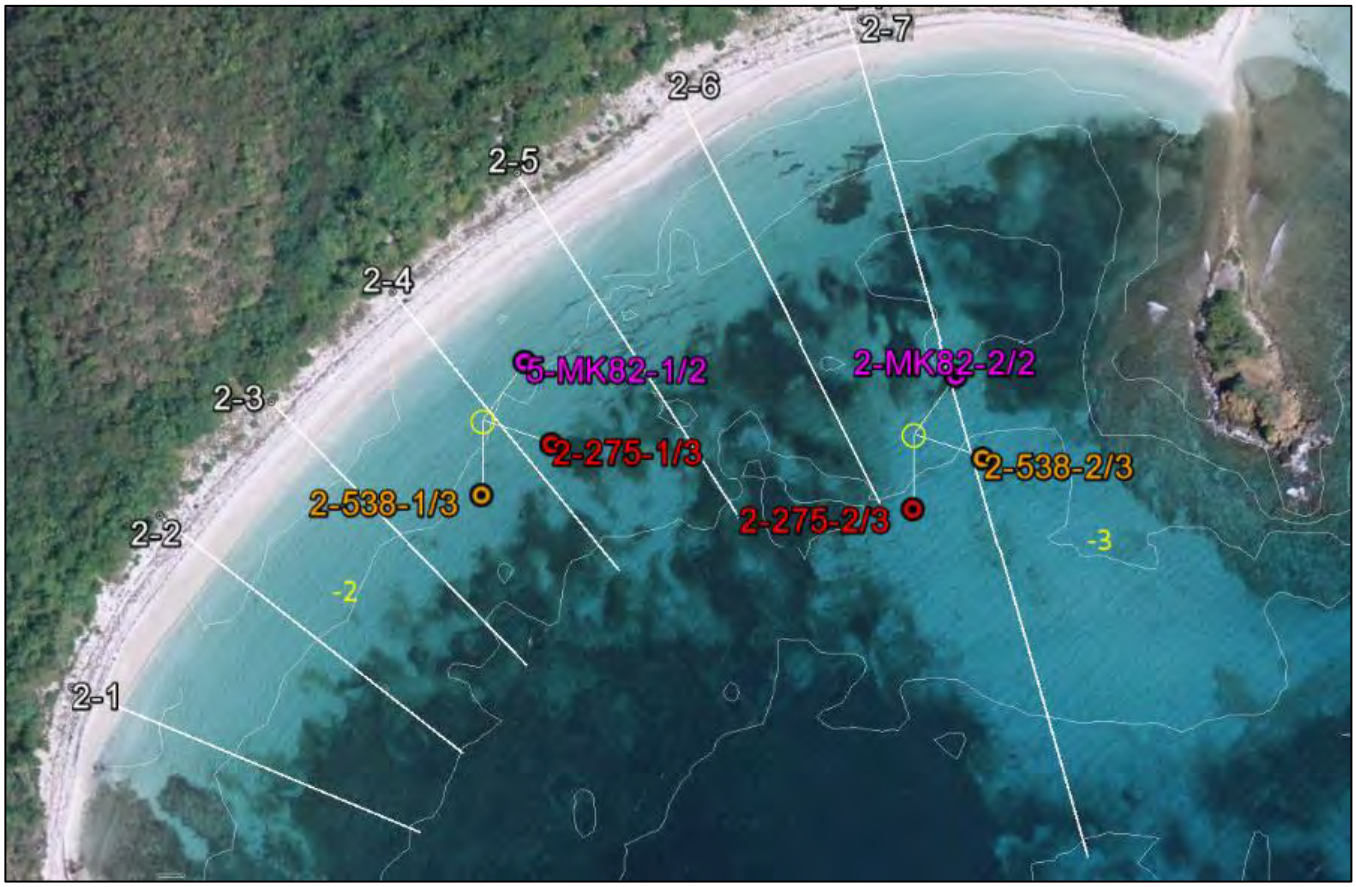

Figure F-8. Surrogate locations at Beach 2, nearshore (5-MK82-1/2 deployed instead of 2-MK82-1/2).

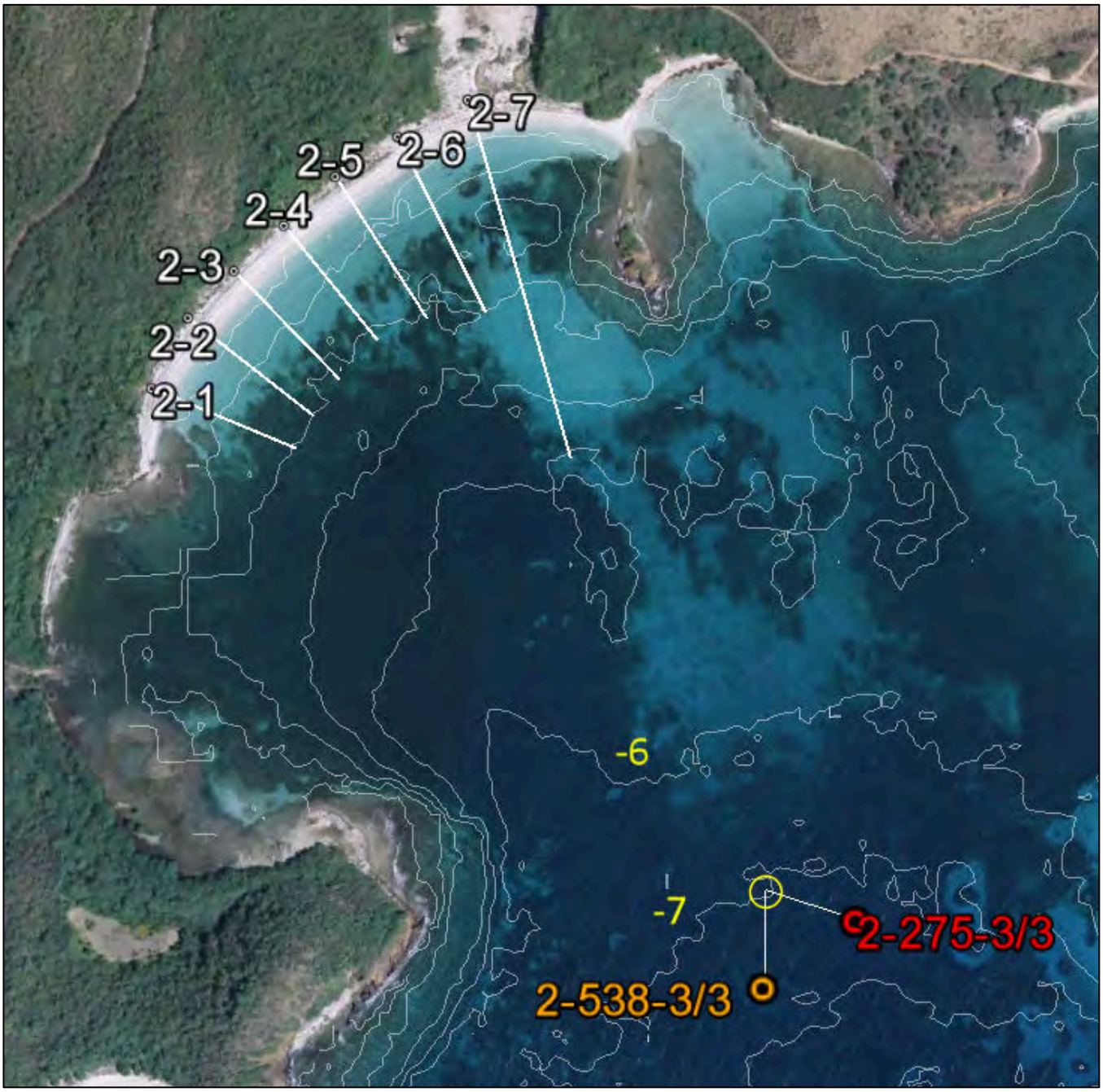

Figure F-9. Surrogate locations at Beach 2.

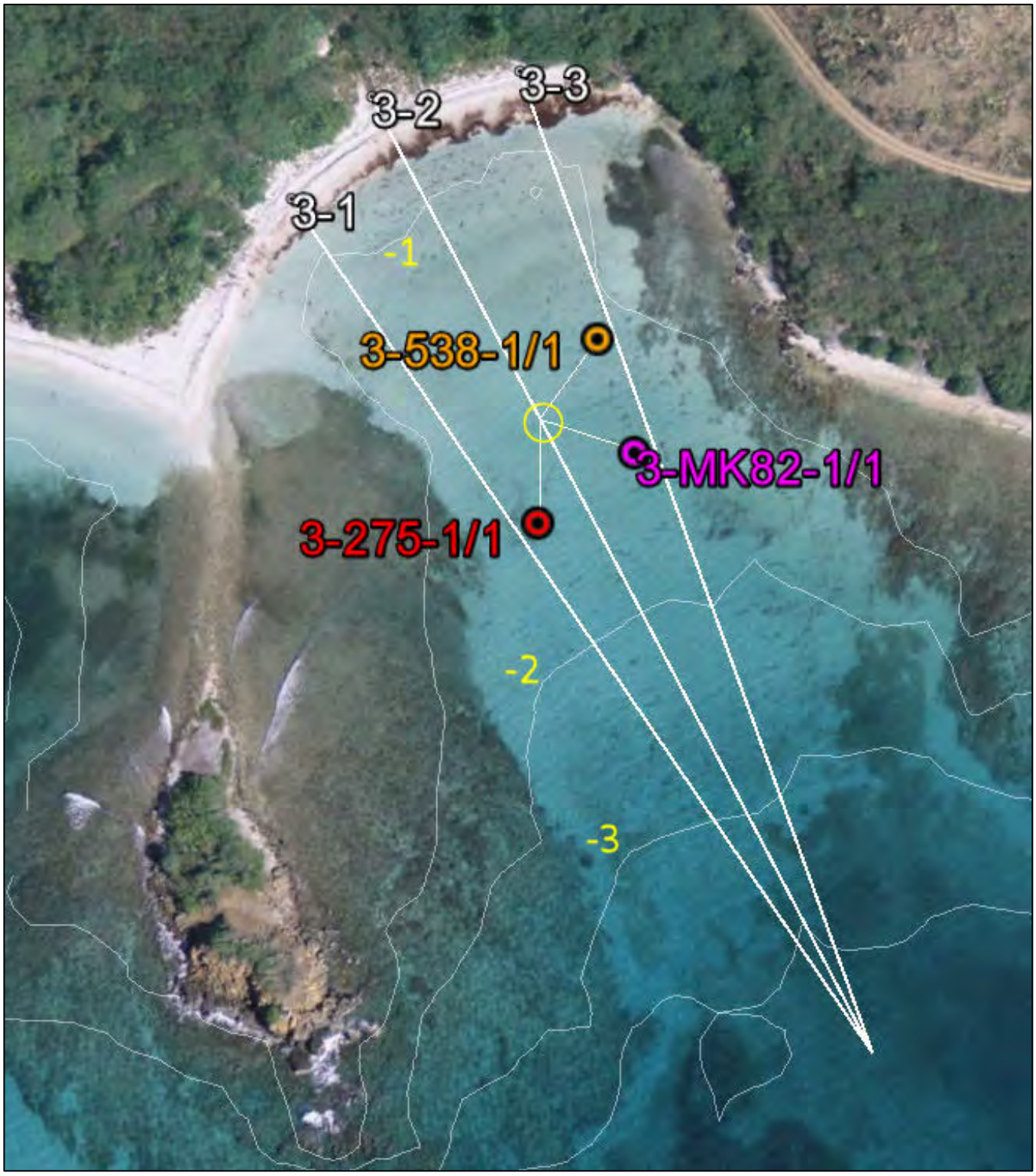

Figure F-10. Surrogate locations at Beach 3.

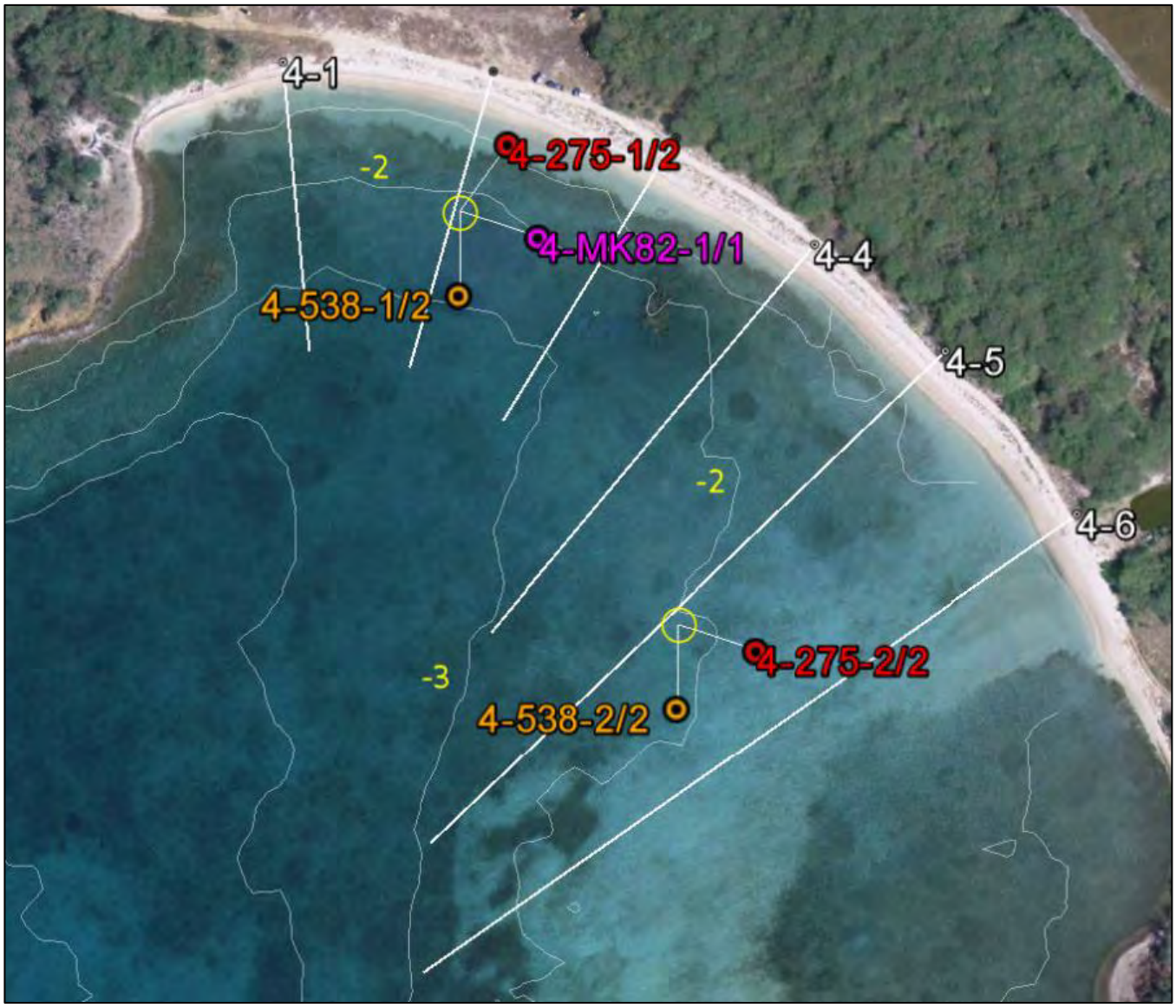

Figure F-11. Surrogate locations at Beach 4.

Figure F-12. Surrogate locations at Beach 5 (14-MK82-1/1 and 2-MK82-1/2 deployed instead of 5-MK82-1/2 and 5-MK82-2/2, respectively).

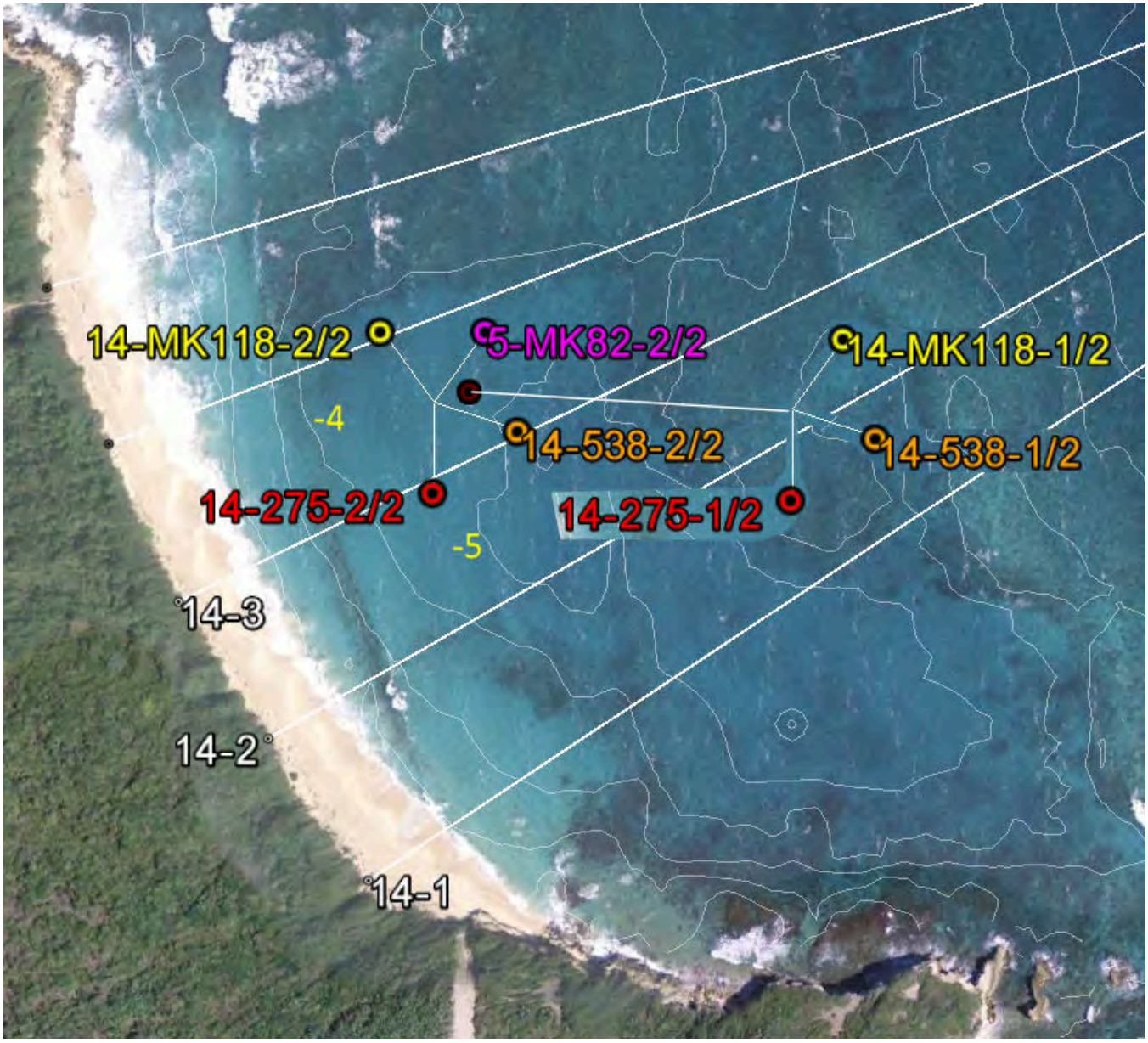

Figure F-13. Surrogate locations at Beach 14 (5-MK82-2/2 deployed instead of 14-MK82-1/1).

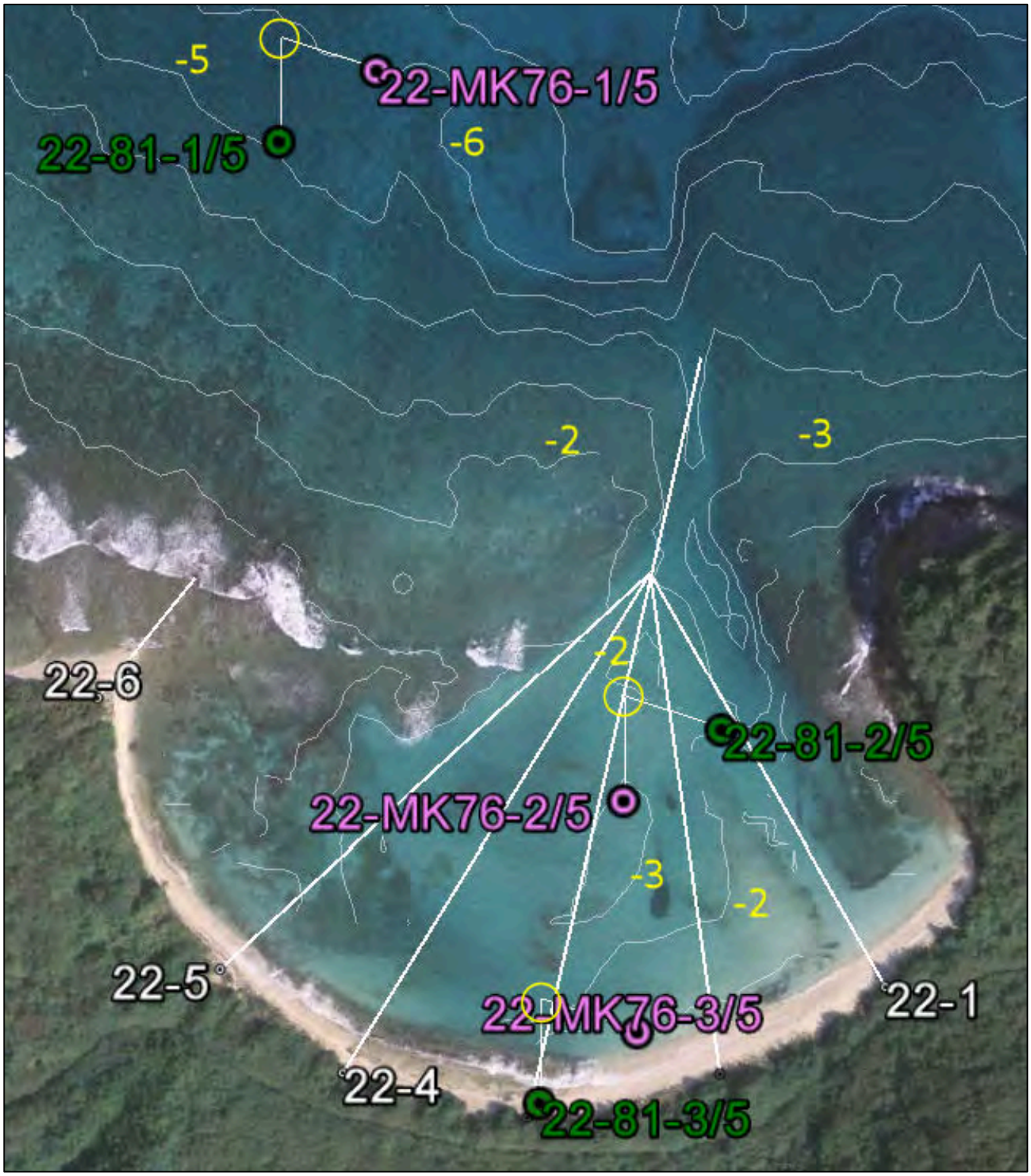

Figure F-14. Surrogate locations at Beach 22 (east).

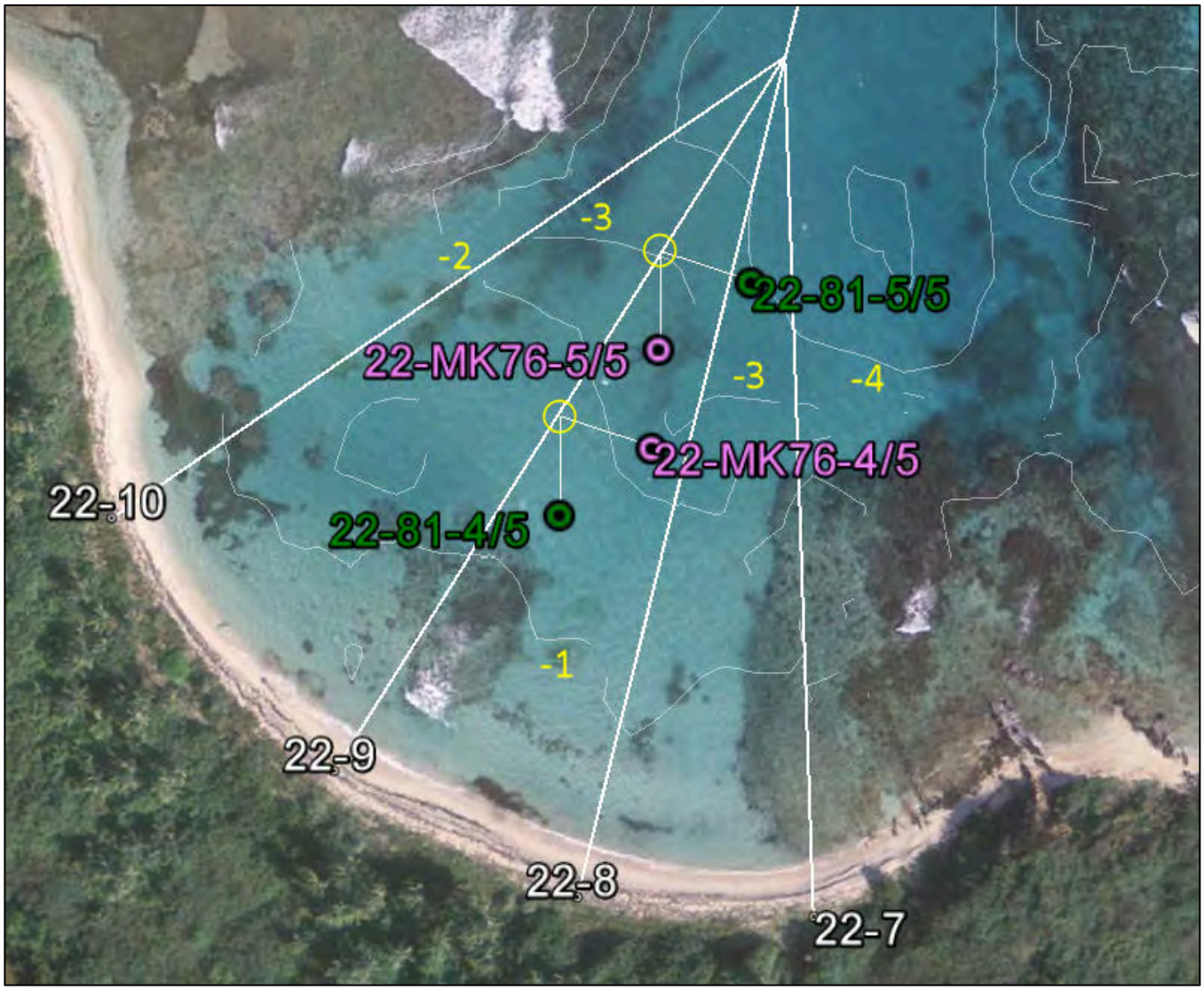

Figure F-15. Surrogate locations at Beach 22 (west).

Figure F-16. Surrogate locations at Beach 24.

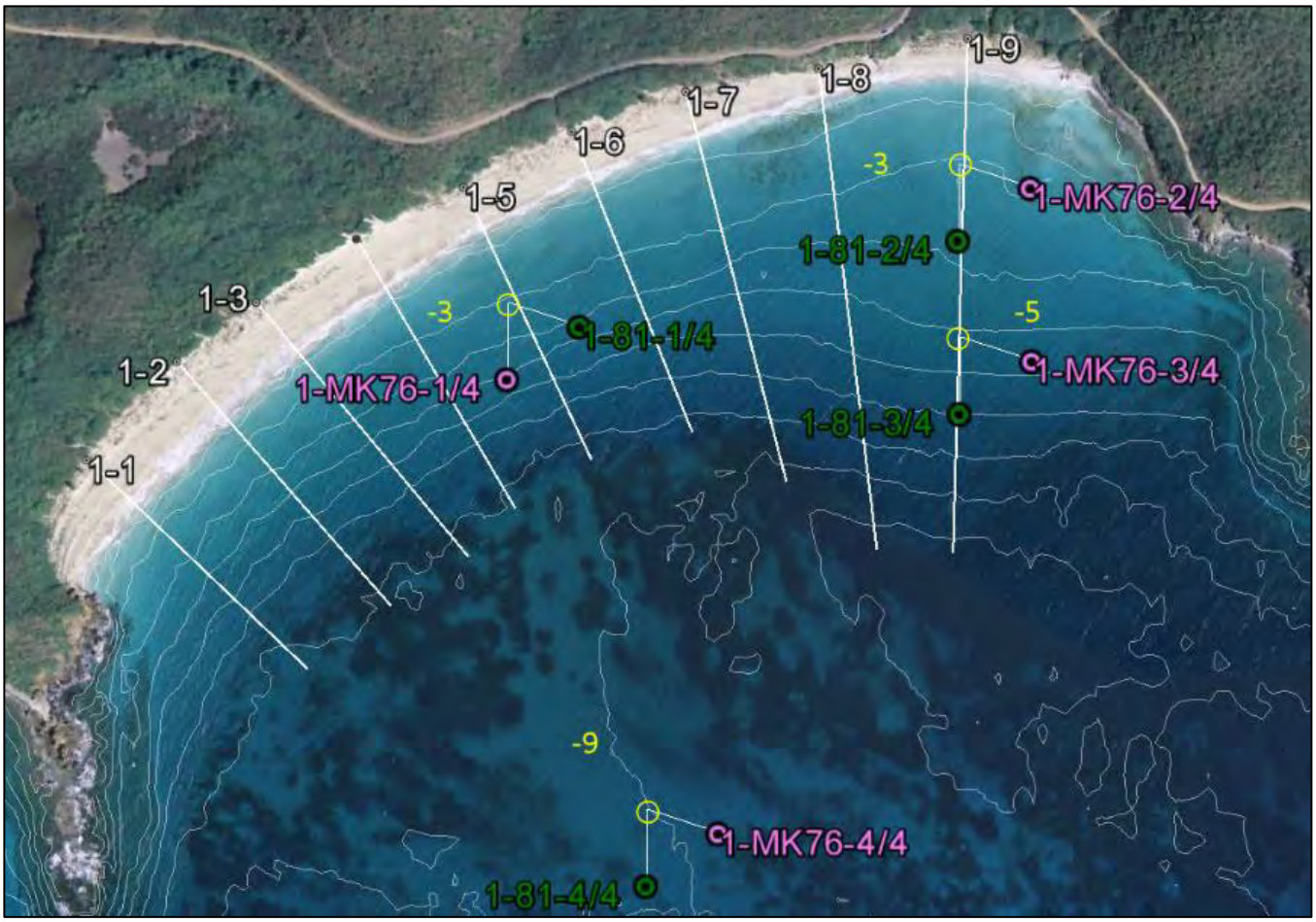

Figure F-17. Surrogate locations at Beach 1.

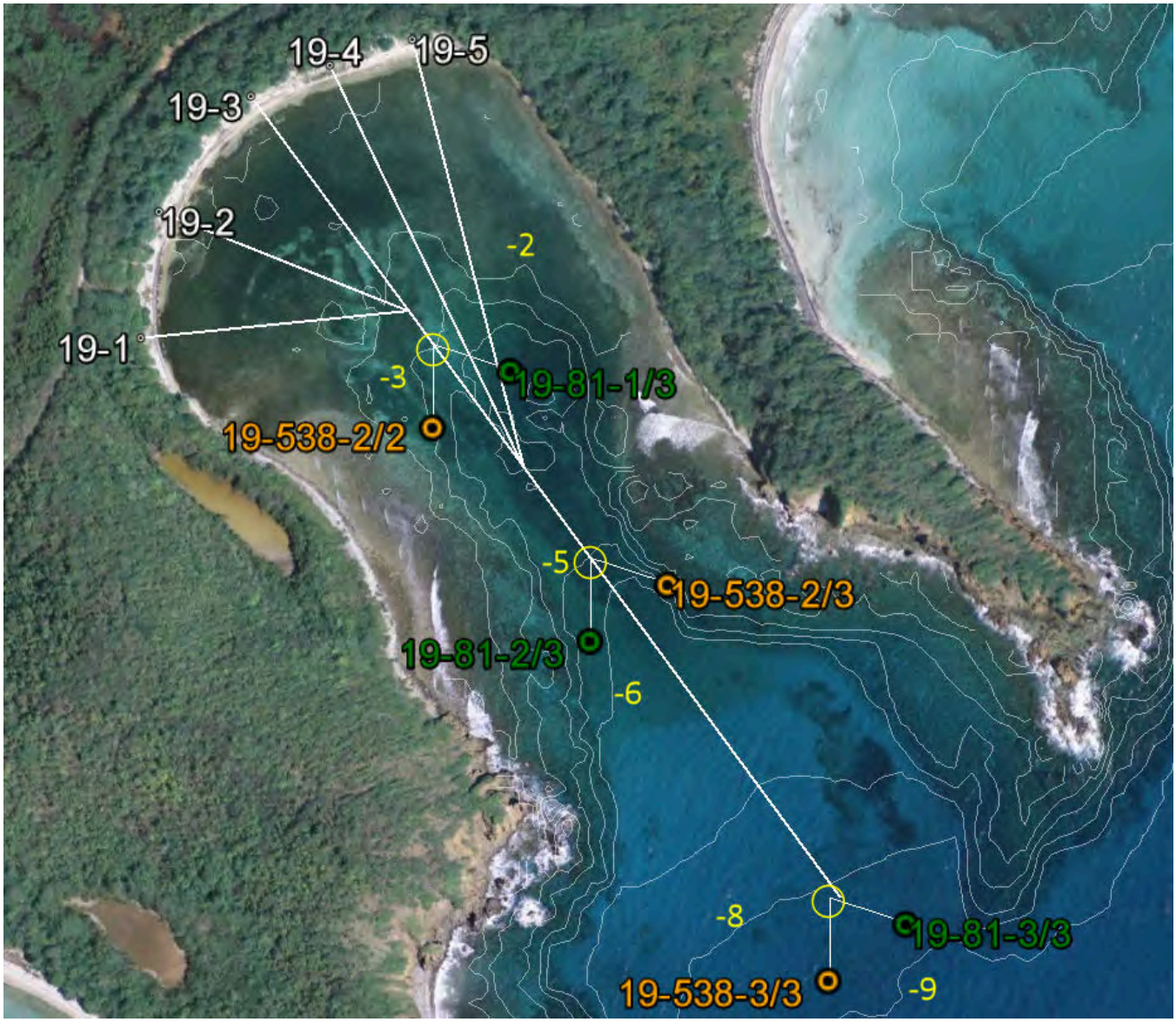

Figure F-18. Surrogate locations at Beach 19 (19-538-2/2 mislabeled; should have been labeled 19-538-1/3).

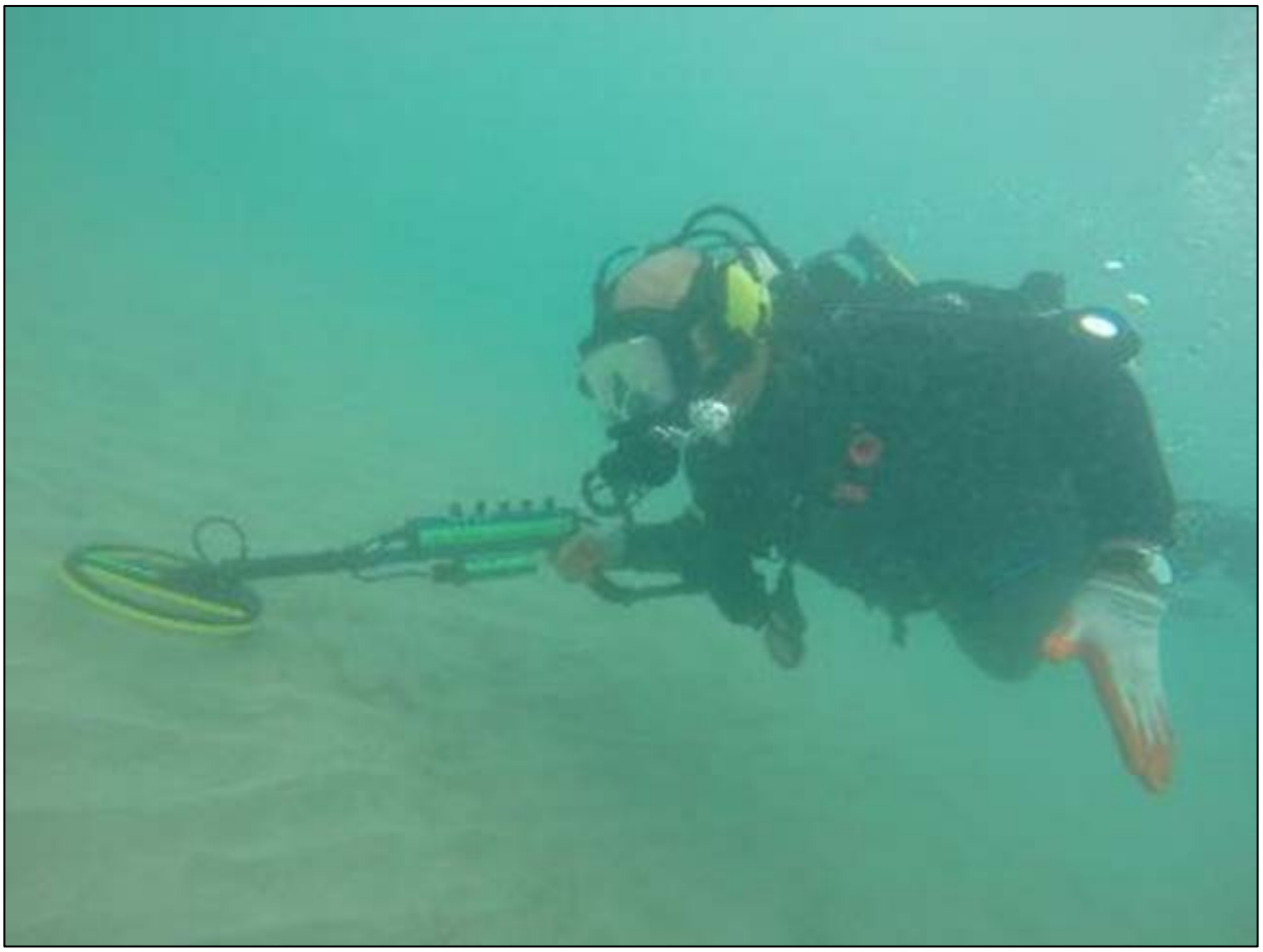

Figure F-19. Munitions diver performing a MEC avoidance survey.

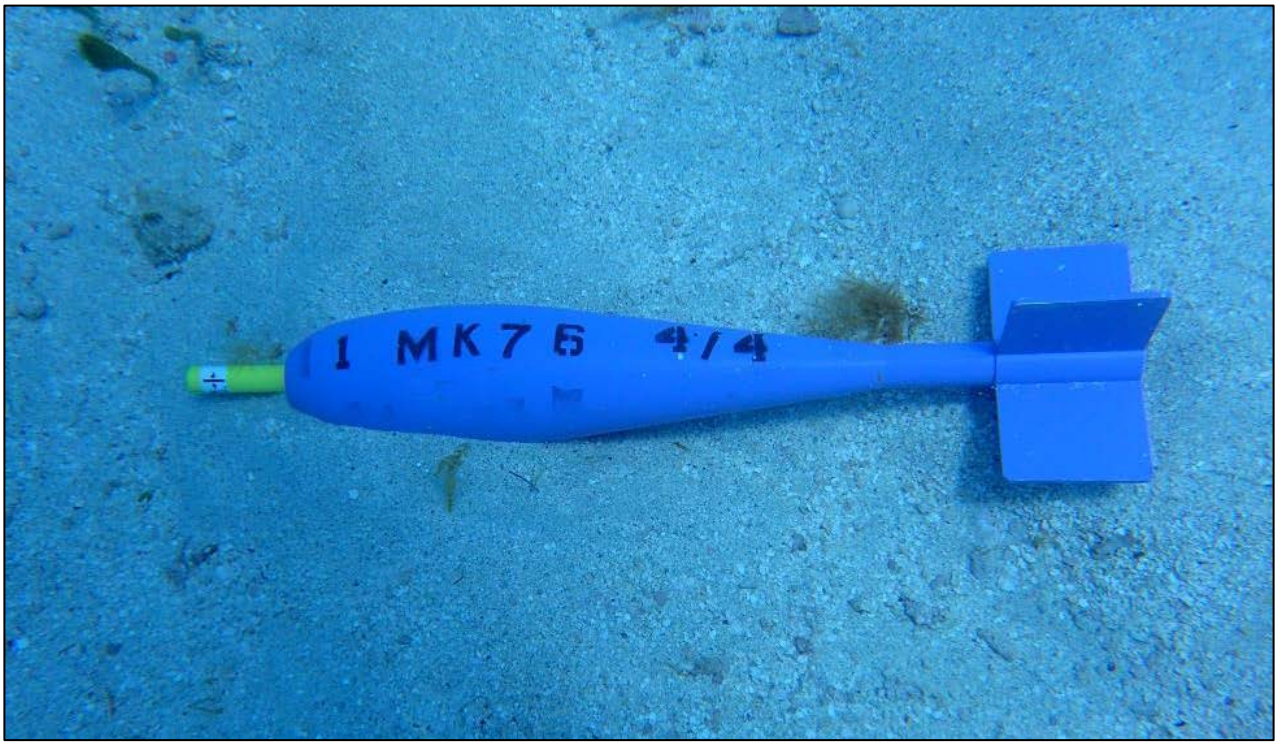

Figure F-20. MK 76 surrogate deployed at Beach 1.

Figure F-21. MK 82 surrogate being deployed with lift bag at Beach 2.

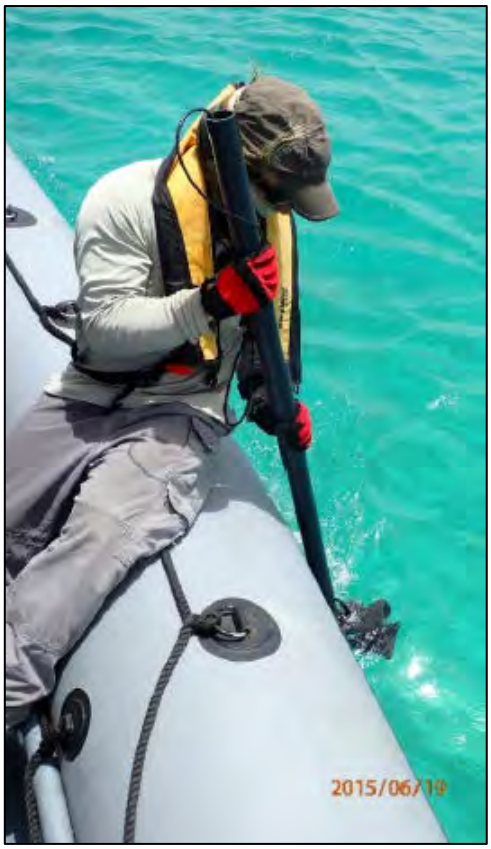

Figure F-22. MANTRAK hydrophone (left), bathyscope (right).

Figure F-23. Depth of burial measurement on a 5-inch 38-caliber projectile surrogate.

Appendix G
Metocean Field Observations

APPENDIX G

Metocean Field Observations

Figure G-1 through **Figure G-6** show the wave and wind conditions from boat crew observations at Live Impact Area (LIA) UXO 2 Beaches 2, 3, 4, 5, 12 and 14; **Figure G-7** through **Figure G-9** for Eastern Maneuver Area (EMA) and Surface Impact Area (SIA) Beaches 22 and 24; **Figure G-10** and **Figure G-11** for South SIA UXO 8 Beaches 1 and 19; and **Figure G-12** for SWMU 4.

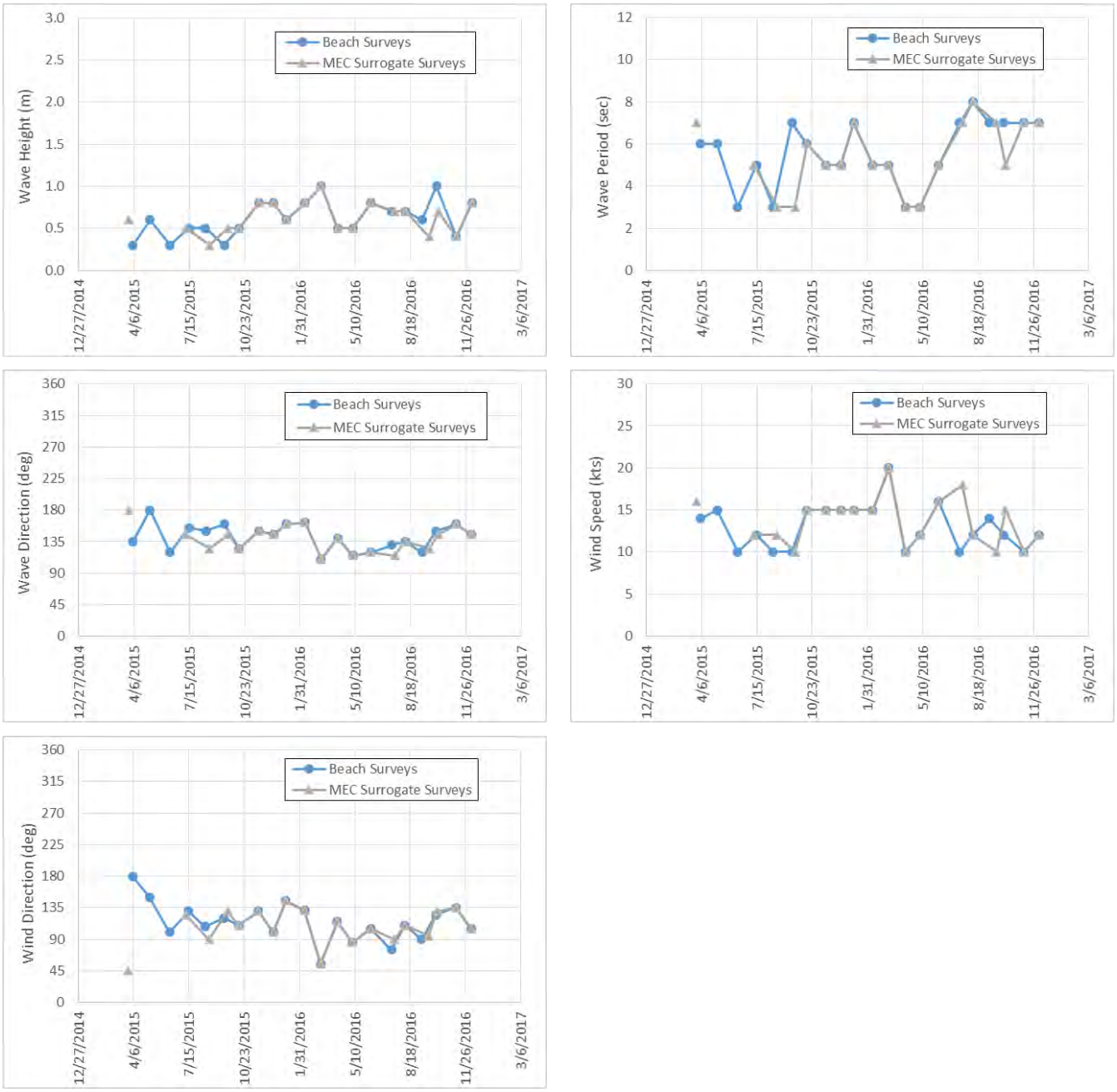

Figure G-1. Wind and wave conditions at Beach 2 from boat crew observations.

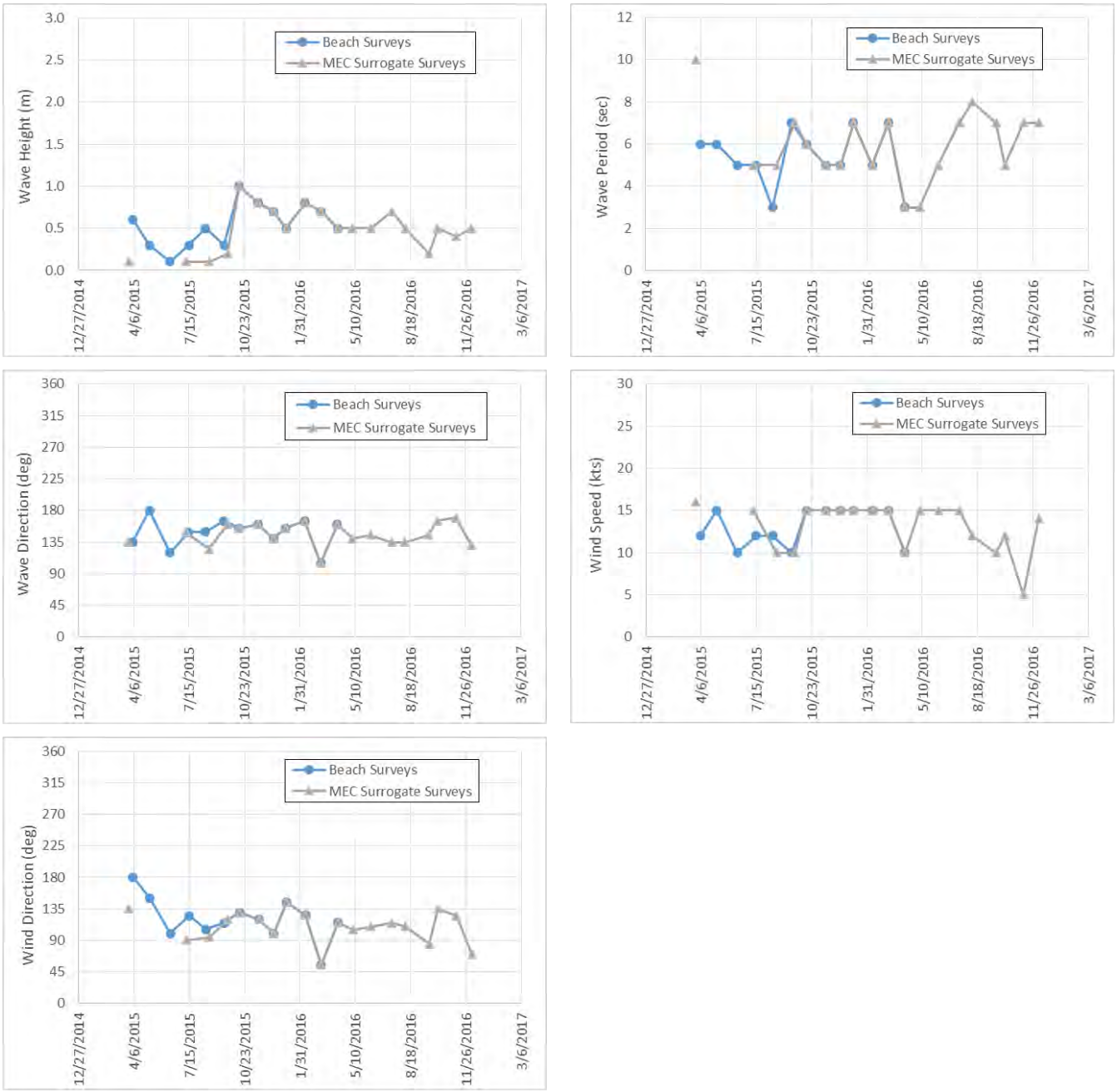

Figure G-2. Wind and wave conditions at Beach 3 from boat crew observations.

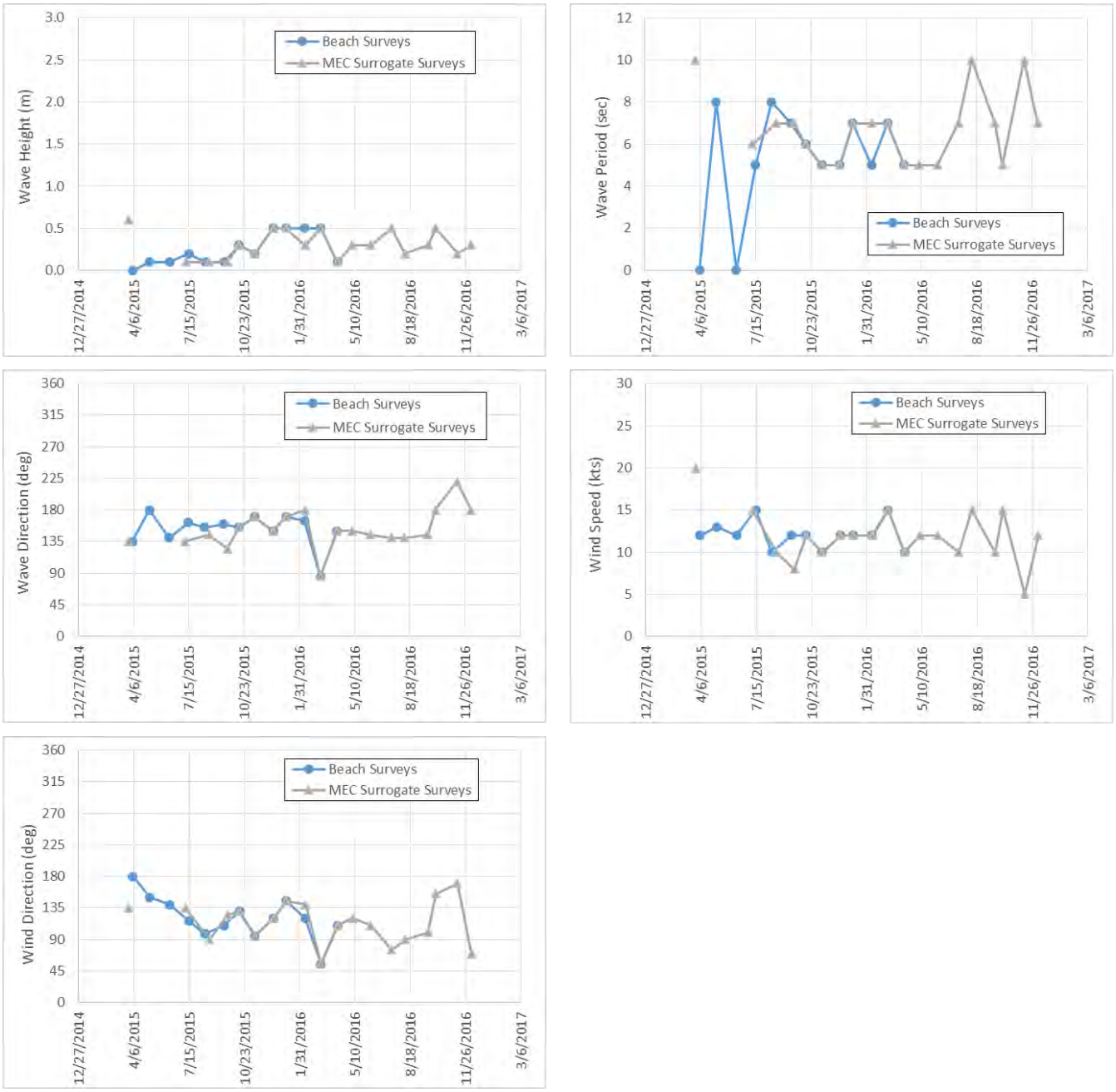

Figure G-3. Wind and wave conditions at Beach 4 from boat crew observations.

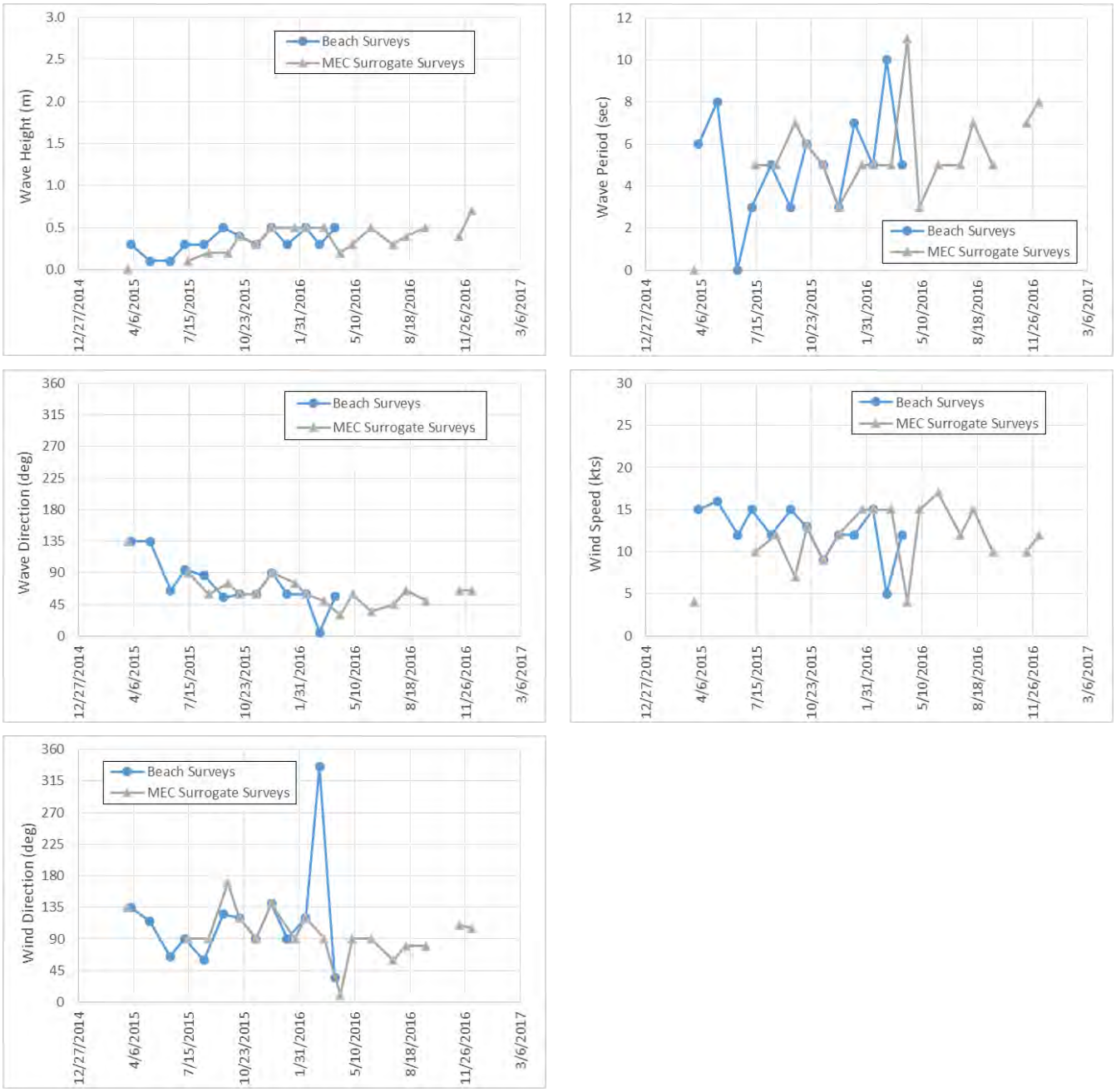

Figure G-4. Wind and wave conditions at Beach 5 from boat crew observations.

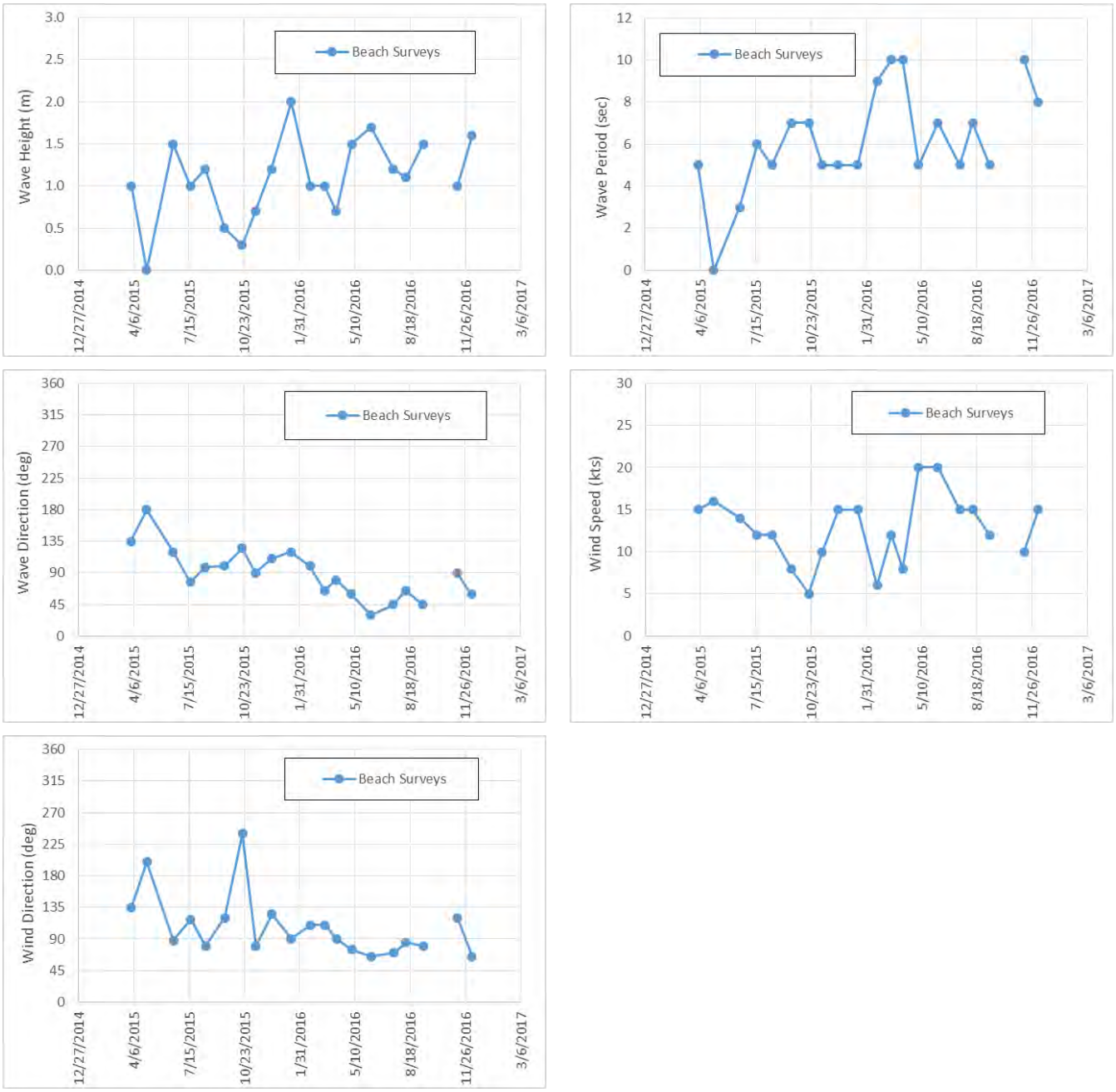

Figure G-5. Wind and wave conditions at Beach 12 from boat crew observations.

Figure G-6. Wind and wave conditions at Beach 14 from boat crew observations.

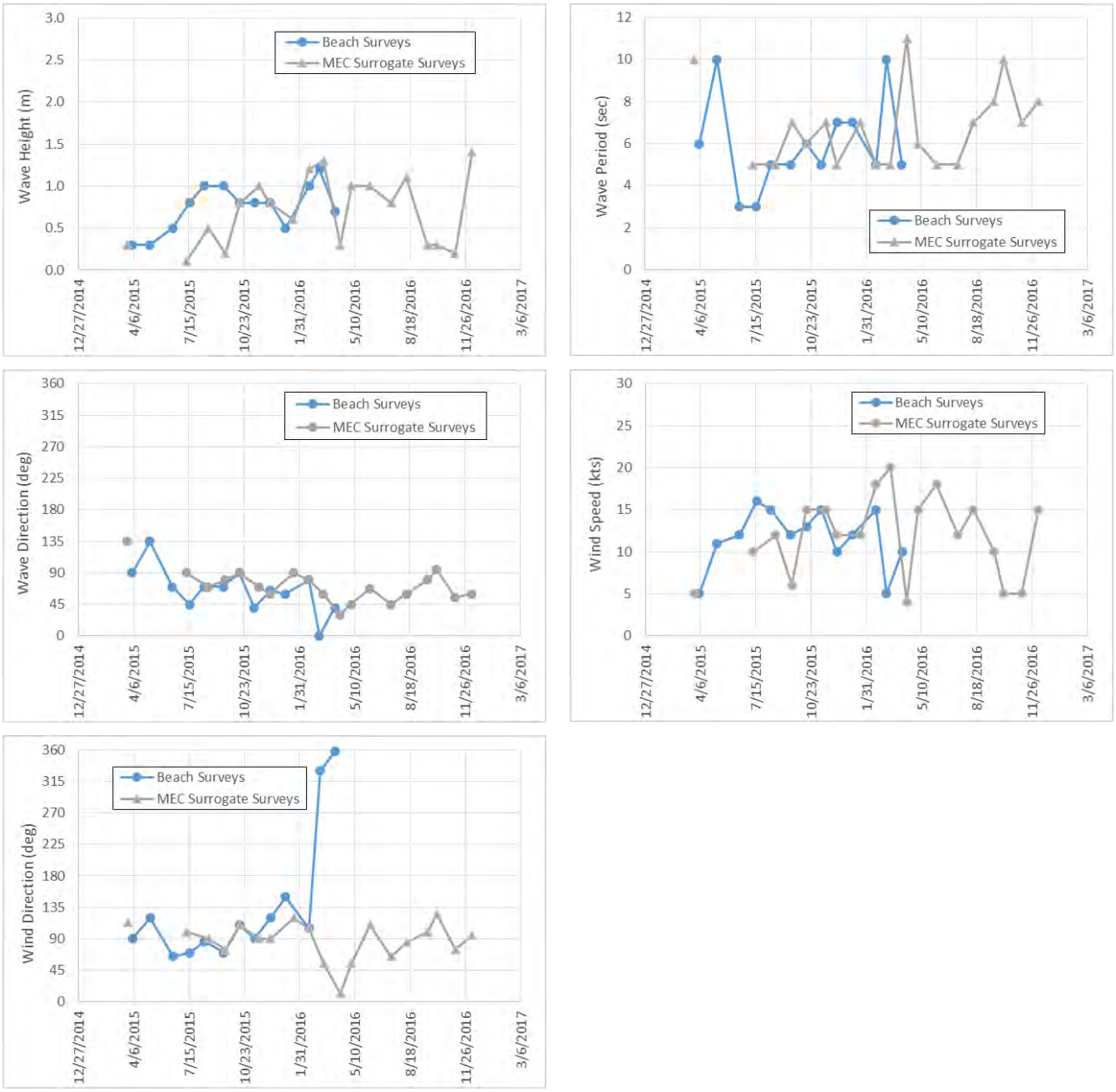

Figure G-7. Wind and wave conditions at Beach 22 (east) from boat crew observations.

Figure G-8. Wind and wave conditions at Beach 22 (west) from boat crew observations.

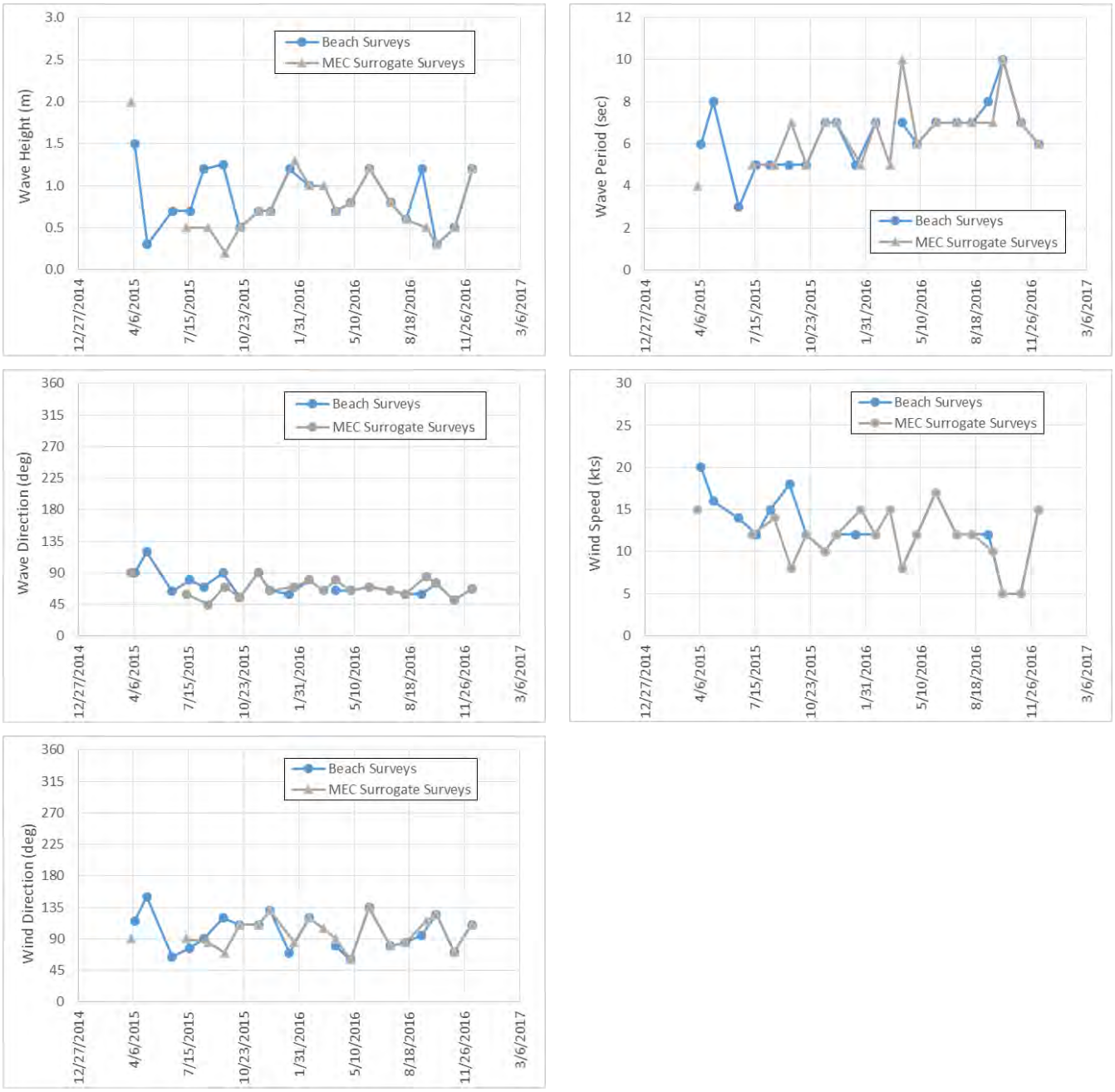

Figure G-9. Wind and wave conditions at Beach 24 from boat crew observations.

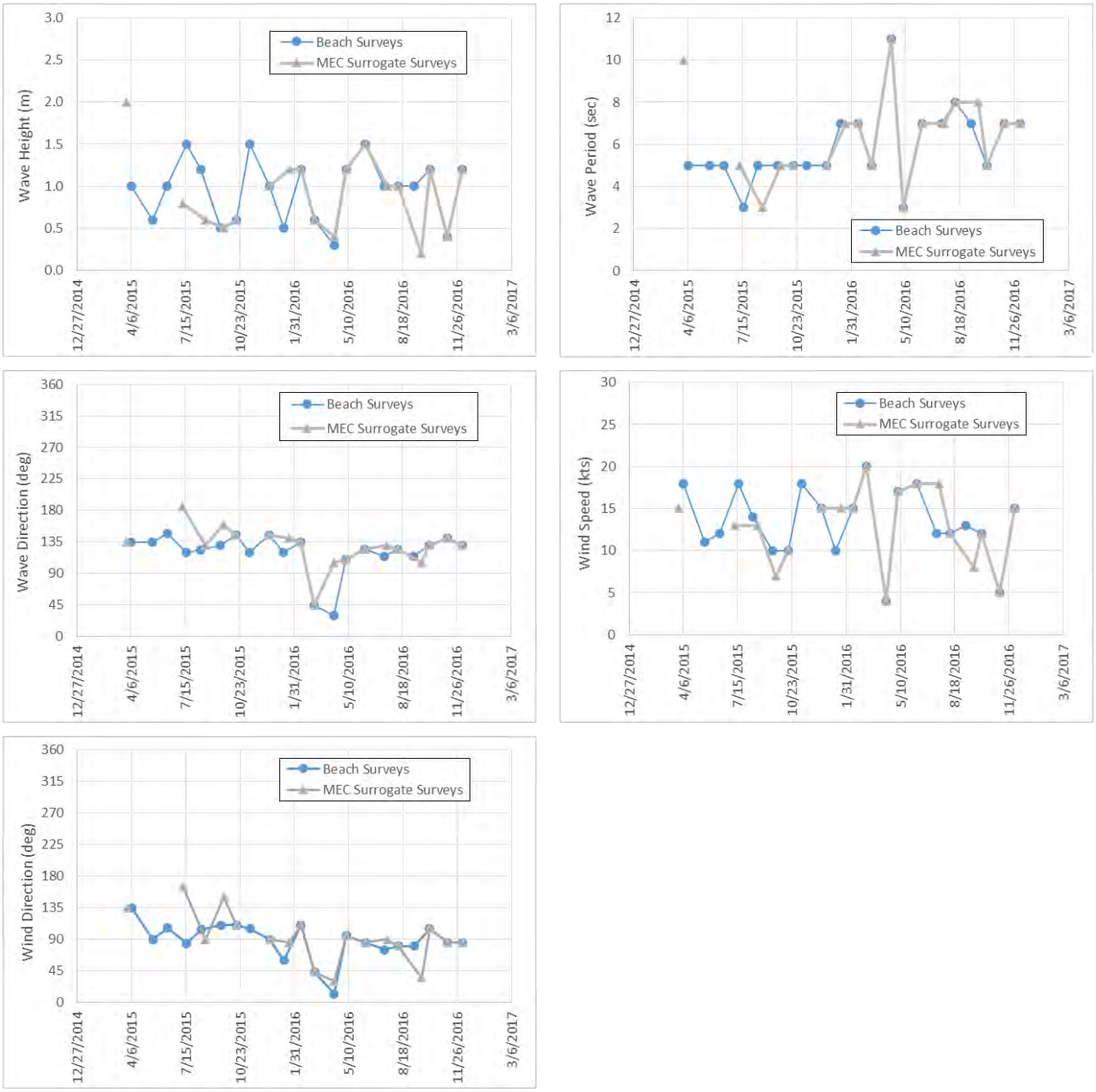

Figure G-10. Wind and wave conditions at Beach 1 from boat crew observations.

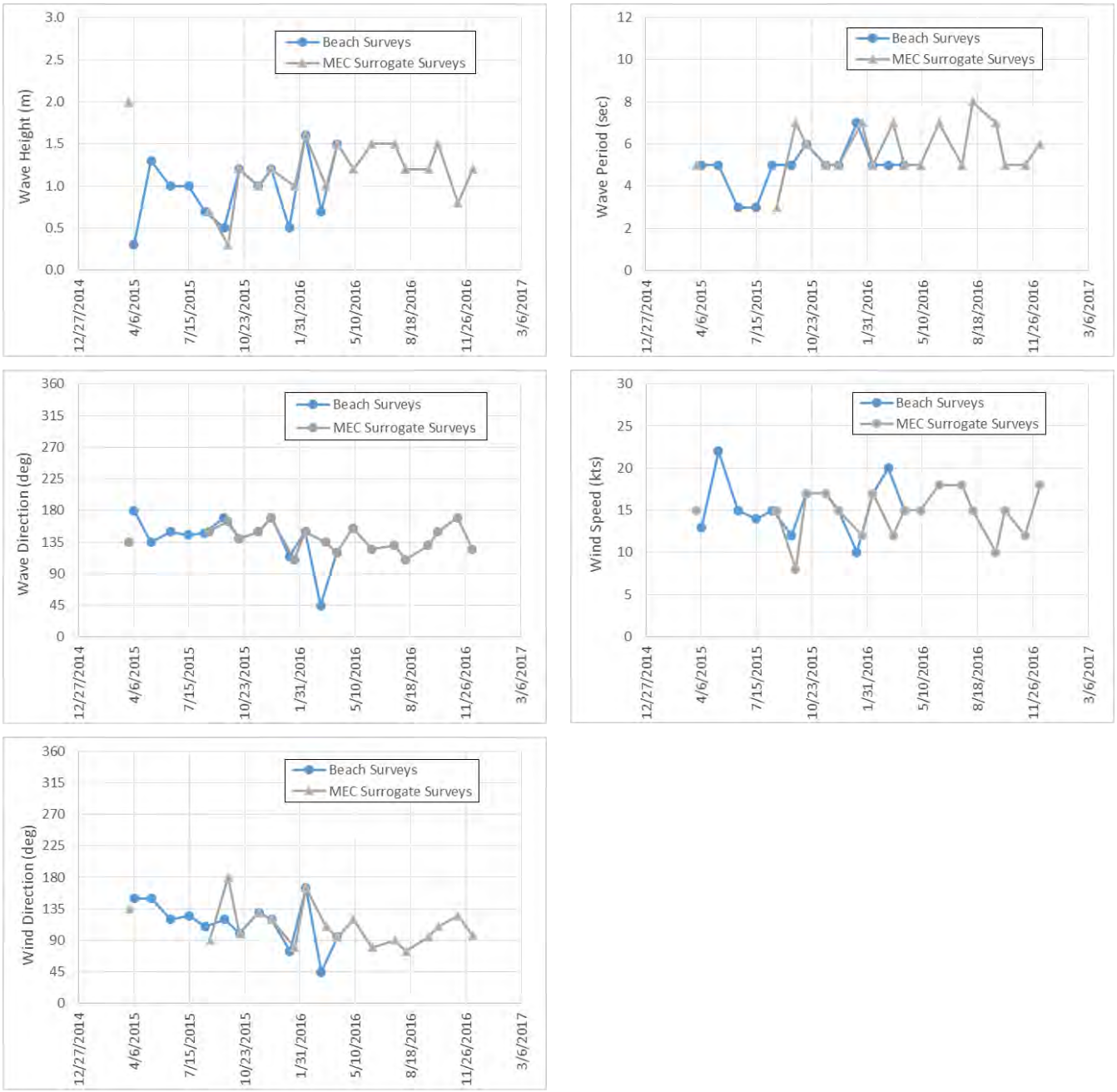

Figure G-11. Wind and wave conditions at Beach 19 from boat crew observations.

Figure G-12. Wind and wave conditions at SWMU 4 from boat crew observations.

Appendix H
Third-party Metocean Data

APPENDIX H

Third-party Metocean Data

The following is a list of the third-party metocean data sources, and links to online station information and data.

National Oceanic and Atmospheric Administration (NOAA) Station 9751639 Charlotte Amalie, VI
https://tidesandcurrents.noaa.gov/stationhome.html?id=9751639

NOAA Station 9752695 Esperanza, PR
https://tidesandcurrents.noaa.gov/stationhome.html?id=9752695

NOAA Station 9752619 Isabel Segunda, PR
https://tidesandcurrents.noaa.gov/stationhome.html?id=9752619

NOAA Station 9753216 Fajardo, PR
https://tidesandcurrents.noaa.gov/stationhome.html?id=9753216

NOAA Station 9754228 Yabucoa Harbor, PR
https://tidesandcurrents.noaa.gov/stationhome.html?id=9754228

National Data Buoy Center (NDBC) Station 41043 NE Puerto Rico
http://www.ndbc.noaa.gov/station_realtime.php?station=41043

NDBC Station 41044 NE St. Martin
http://www.ndbc.noaa.gov/station_realtime.php?station=41044

NDBC Station 42060 Caribbean Valley
http://www.ndbc.noaa.gov/station_realtime.php?station=42060

NDBC Station 42059 Easter Caribbean Sea
http://www.ndbc.noaa.gov/station_realtime.php?station=42059

NDBC Station 41051 South of St. Thomas
http://www.ndbc.noaa.gov/station_realtime.php?station=41051

NDBC Station 41052 South of St. John
http://www.ndbc.noaa.gov/station_realtime.php?station=41052

NDBC Station 41056 S Vieques Island
http://www.ndbc.noaa.gov/station_realtime.php?station=41056

Appendix I
Wave Analyses

APPENDIX I

Wave Analyses

1. Frequency Analysis

Figure I-1 through **Figure I-6** show the frequency of occurrence of the significant wave height, period, and mean wave direction at acoustic wave and current sensor (AWAC)-N during the Beach Dynamics Investigation (BDI), per season; **Figure I-7** through **Figure I-12** at AWAC-E; and **Figure I-13** through **Figure I-18** at AWAC-S.

2. Typicality Analysis

The typicality of the wave climate during the BDI was analyzed using wave data at National Data Buoy Center (NDBC) Station 41043 NE Puerto Rico and quantile-quantile (Q-Q) plots, the location of this station is shown in **Figure I-19**.

A Q-Q plot is a graphical technique for determining if two data sets come from populations with a common distribution. In a Q-Q plot, quantiles of the first data set are plotted against the quantiles of the second data set. If the quantiles in the Q-Q plot depart from the 1:1 sloped straight line it can be concluded that the distributions are different. **Figure I-20** shows the Q-Q of significant wave heights measured at NDBC Station 41043 during the BDI from January 1, 2015, to December 31, 2016, versus wave heights measured from May 1, 2012, to December 31, 2014. **Figure I-21** shows the Q-Q plot for the peak period. The agreement with the 1:1 slope straight line is very good for both, significant wave heights and peak periods. Therefore, in the absence of longer wave records that could permit a more detailed analysis, it can be concluded that the wave climate during the BDI was typical. Since wind is the mechanism of waves that reach Vieques, it could be inferred that the wind climate, along with wind-induced currents were also typical during the BDI.

3. Hurricane Maria Wave and Storm Surge Modeling

Hurricane Maria was one of the most devastating hurricanes to hit Vieques in recent times. At the time of its passage on September 20, 2017, the BDI was completed and no wave measurements from the BDI or third-party sensors were available. To allow for the correlation of the hurricane's waves and storm surge with the beach changes these produced, combined wave and storm surge modeling was performed.

Prior to the wave and storm surge modeling, the hurricane's time and space varying wind and atmospheric pressure fields were computed with MIKE 21 Cyclone Wind Generation model (DHI, 2017a). In MIKE 21 Cyclone, wind and atmospheric pressure fields are computed with parametric models based on time histories of hurricane parameters such as track location, forward speed, central pressure, radius to maximum wind, etc. The wind and pressure fields computed with MIKE 21 Cyclone were subsequently used with the MIKE 21 Spectral Wave (SW) model (DHI, 2017b) combined with the MIKE 21 Hydrodynamic (HD) Flexible Mesh (FM) model (DHI, 2017c) to compute significant wave heights, peak periods, mean wave directions, and water levels around Vieques, and at the BDI beaches in particular.

The wave conditions at each beach, reported in Tables 5-3 through 5-15, were estimated from observations and the 2015 wave hindcast. The 2015 wave hindcast was developed with a spectral wave model propagating the wave heights measured in 2015 at the three AWAC locations to the beaches.

Figure I-22 shows the domain for both the MIKE 21 Cyclone and SW-HD FM models, the mesh used for the SW-HD FM models, and the bathymetry developed for the BDI (CH2M, 2014). The domain covers part of the Caribbean Sea and North Atlantic Ocean to include the full development of the hurricane wind and pressure fields, and the mesh resolution increases from the offshore to the nearshore around the Vieques island. The model has five open boundaries where, predicted astronomical tide generated from the Global Tide Model (GTM) (DHI, 2017a), were prescribed. The GTM is a 0.125 x 0.125-degree resolution model based on 10 constituents and radar satellite

measurements. Hurricane Maria parameters were obtained from the National Hurricane Center's website (NHC, 2017).

Table I-1 lists the parameters adopted for the MIKE 21 Cyclone model, **Table I-2** and **Table I-3** the parameters for MIKE 21 SW and HD FM, respectively; and **Table I-4** Hurricane Maria parameters.

Table I-1. MIKE 21 Cyclone model parameters

Parameter	Description
model	Holland, single vortex
R_{max}	radius to maximum wind, Vickery et al. (2000)
B	Holland's pressure profile parameter, Vickery et al. (2008)
Pn	neutral pressure (1,013 hPa)

Table I-2. MIKE 21 SW model parameters

Parameter	Description
basic equations	fully spectral, instationary
directional discretization	direction sector in sixteen 22.5-degree bins
water level and current condition	from MIKE 21 HD FM
diffraction	smoothing factor = 1
wave breaking	gamma (depth-limited) = 0.8
bottom friction	Nikuradse roughness length = 0.04 m
initial condition	JONSWAP, default values
wind forcing	uncoupled, from MIKE 21 Cyclone

Table I-3. MIKE 21 HD FM model parameters

Parameter	Description
solution technique	low-order numerical advection scheme
flood and dry	included
eddy viscosity	Smagorinsky formulation, Cs = 0.28
bed resistance	constant Manning, M = 40
Coriolis type	varying in domain
wind	from MIKE 21 Cyclone
wave radiation	from MIKE 21 SW
initial condition	hot start from a 2 week spin up model
boundary conditions	Global Tide Model (GTM)

Table I-4. Hurricane Maria parameters.

Date and Time	Longitude	Latitude	Rmax (km)	Wind Speed [a] (m/s)	Central Pressure (hPa)	B
9/18/2017 18:00	-60.4	14.9	21.31	56.6	956	1.58
9/19/2017 0:00	-61.1	15.3	17.07	72.0	924	1.59
9/19/2017 6:00	-61.9	15.8	19.86	69.4	940	1.57
9/19/2017 12:00	-62.7	16.1	18.72	72.0	931	1.58
9/19/2017 18:00	-63.6	16.6	17.32	74.6	920	1.58
9/20/2017 0:00	-64.3	17	15.76	77.2	909	1.58
9/20/2017 6:00	-65.1	17.6	16.82	72.0	913	1.57
9/20/2017 12:00	-66.1	18.2	19.66	64.3	927	1.54
9/20/2017 18:00	-67	18.6	25.08	48.9	959	1.51
9/21/2017 0:00	-67.6	18.9	25.24	48.9	958	1.50
9/21/2017 6:00	-68.1	19.4	25.89	51.4	959	1.49
9/21/2017 12:00	-68.8	19.9	26.40	51.4	959	1.49
9/21/2017 18:00	-69.5	20.5	27.19	54.0	960	1.47
9/22/2017 0:00	-70	20.8	26.42	56.6	953	1.47
9/22/2017 6:00	-70.5	21.2	27.80	56.6	959	1.46
9/22/2017 12:00	-70.9	21.9	28.42	56.6	958	1.45
9/22/2017 18:00	-71.2	22.8	29.61	56.6	959	1.43
9/23/2017 0:00	-71.6	23.7	29.63	56.6	953	1.42

a. 10-minute average

B = Holland's pressure profile parameter
hPa = hectopascal
km = kilometer
m/s = meters per second
Rmax = radius to maximum wind

MIKE 21 Cyclone modeling results included time histories of wind and pressure fields, while MIKE 21 SW-HD FM included time histories of wave parameters and water levels every 5 minutes. **Figure I-23** shows Hurricane Maria track and wind and pressure fields, and **Figure I-24** shows a comparison of measured and predicted wave heights at NDBC Station 41052 South of Saint John, VI (NDBC, 2018). Despite the hurricane model not being calibrated, the predicted significant wave height of 7.8 meters (m) compared well with the measured significant wave height of 7.9 m.

For each of the BDI beaches on the south coast (Beaches 1, 2, 3, 4, and 19), **Figure I-25** to **Figure I-30** show the significant wave heights (Hs) and mean wave directions (MWD), and storm surge at the time of the highest waves during Hurricane Maria.

Figure I-31 to **Figure I-34** show the significant Hs and MWD, and storm surge at the time of the highest waves during Hurricane Maria for the BDI beaches on the east coast (Beaches 12 and 14).

Figure I-35 to **Figure I-40** show the significant Hs and MWD, and storm surge at the time of the highest waves during Hurricane Maria for the BDI beaches on the north coast (Beaches 5, 22, and 24).

Figure I-41 to **Figure I-44** show the significant Hs and MWD, and storm surge at the time of the highest waves during Hurricane Maria for the BDI beaches on the west coast (Solid Waste Management Unit [SWMU] 4 southwest- and west-facing).

4. References

CH2M HILL, Inc. (CH2M). 2014*. Quality Assurance Project Plan Beach Dynamics Investigation Eleven Beaches at the Former Vieques Naval Training Range (VNTR) and the Former Naval Ammunition Support Detachment (NASD), Atlantic Fleet Weapons Training Area – Vieques, Vieques, Puerto Rico.* February.

Danish Hydraulic Institute (DHI). 2017a. *MIKE 21 Toolbox User Guide*. DHI Water & Environment.

DHI. 2017b. *MIKE 21 Spectral Wave Model Module User Guide*. DHI Water & Environment.

DHI. 2017c. *MIKE 21 Flow Model FM – Hydrodynamic Module User Guide*. DHI Water & Environment.

National Data Buoy Center (NDBC). 2018. Station 41052. http://www.ndbc.noaa.gov/station_page.php?station=41052. Accessed February 15, 2018.

National Hurricane Center (NHC). 2017. Hurricane Maria Track. https://www.nhc.noaa.gov/gis/archive_besttrack_results.php?id=al15&year=2017&name=Hurricane MARIA

Vickery, P.J. and D. Wadhera. 2008. *Statistical Models of Holland Pressure Profile Parameter and Radius to Maximum Winds of Hurricanes from Flight-Level Pressure and H*Wind Data*. Journal of Applied Meteorology and Climatology, October 2008, Vol. 47, 2497-2517.

Figures

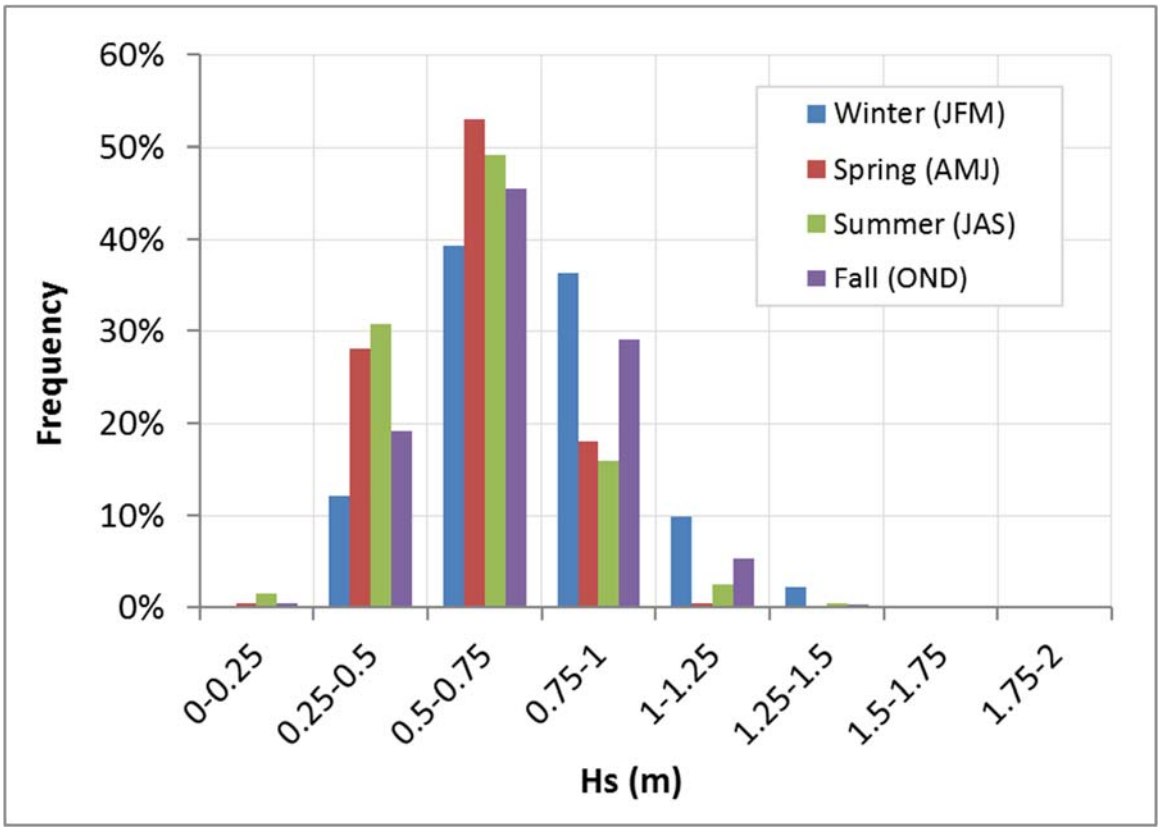

Figure I-1. Frequency of Hs at AWAC-N.

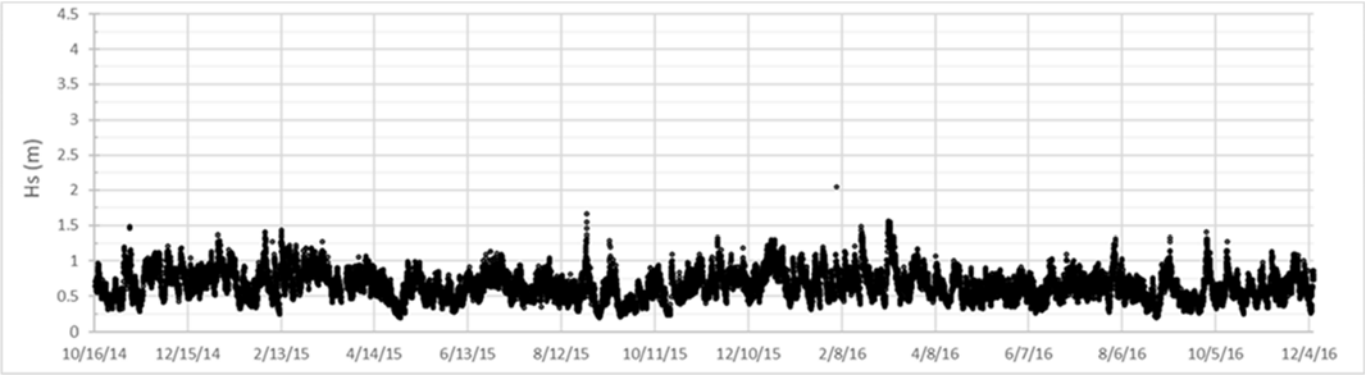

Figure I-2. Time history of Hs at AWAC-N.

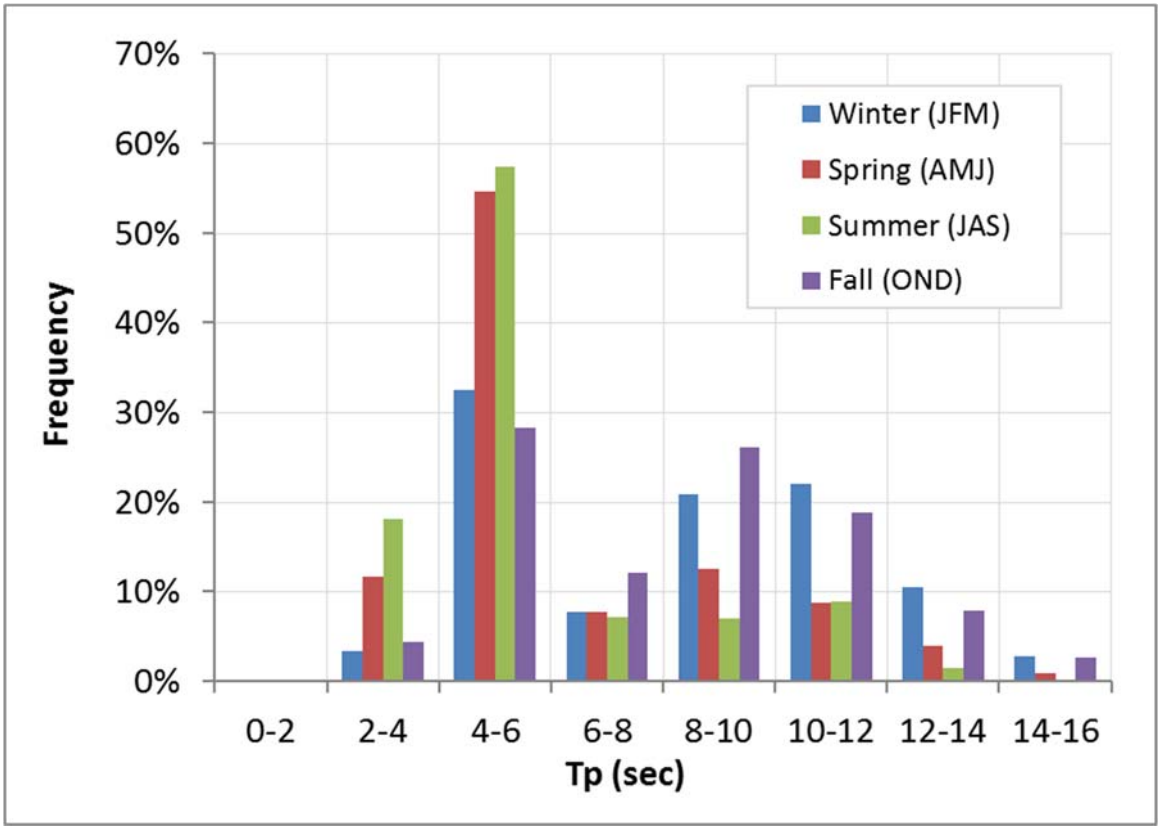

Figure I-3. Frequency of Tp at AWAC-N.

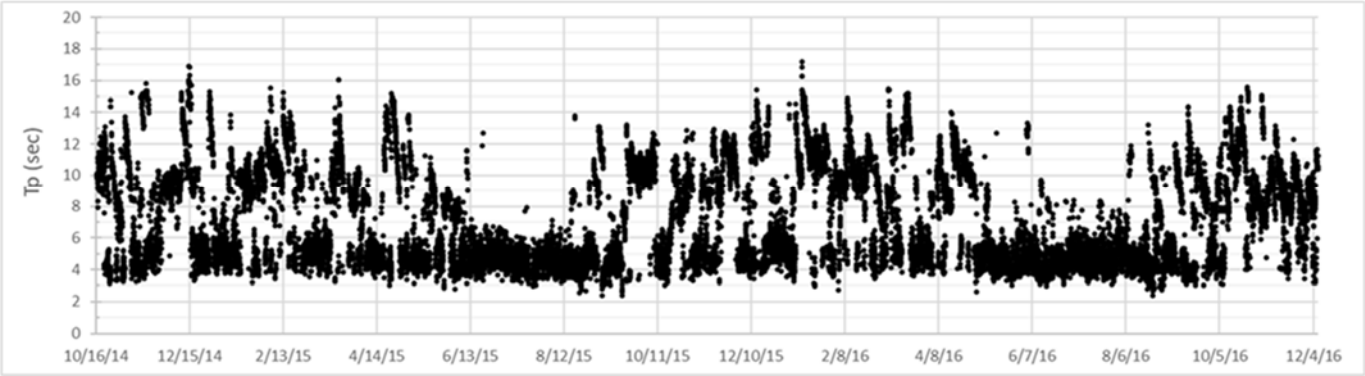

Figure I-4. Time history of Tp at AWAC-N.

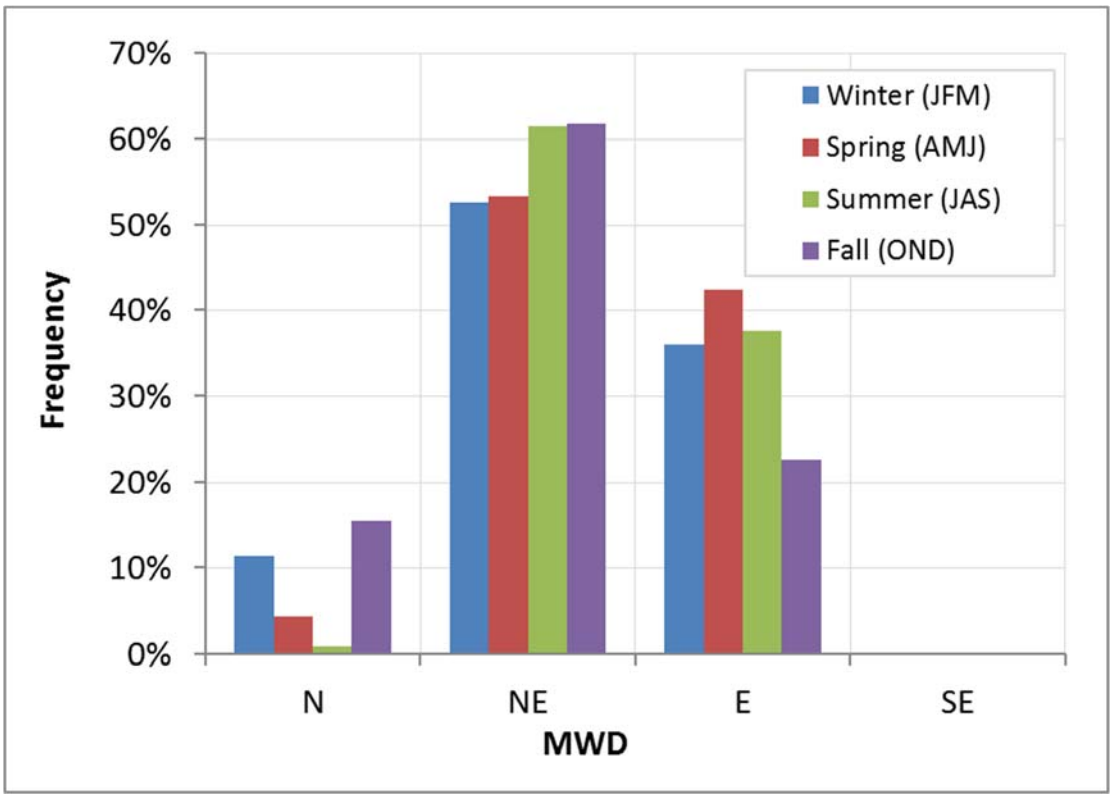

Figure I-5. Frequency of MWD at AWAC-N.

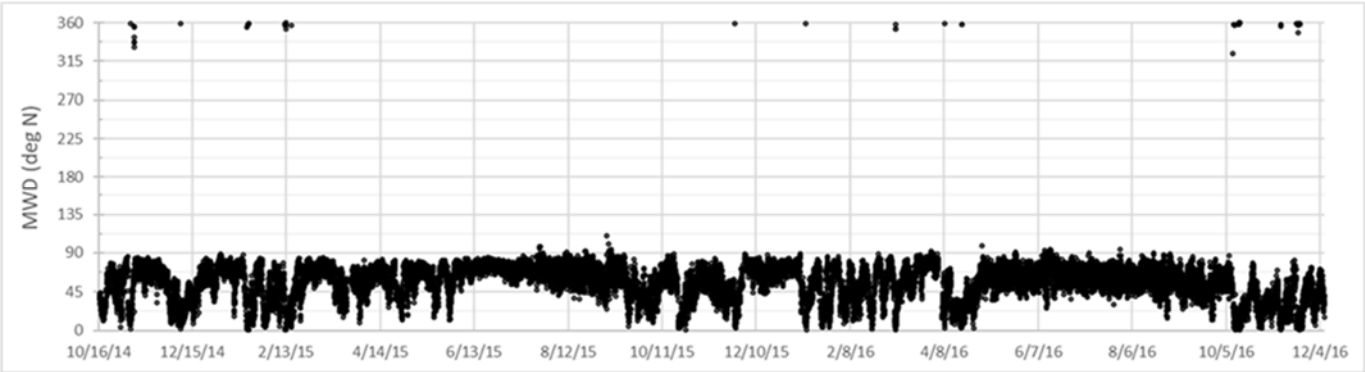

Figure I-6. Time history of MWD at AWAC-N.

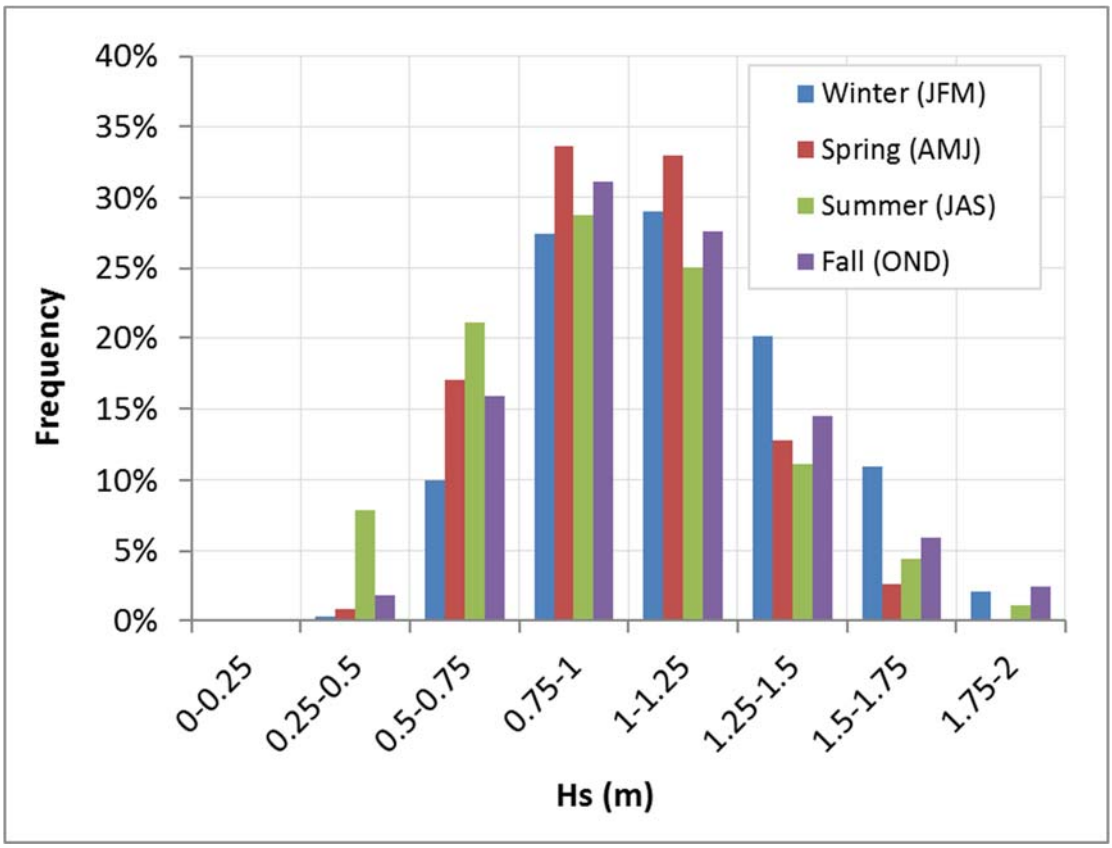

Figure I-7. Frequency of Hs at AWAC-E.

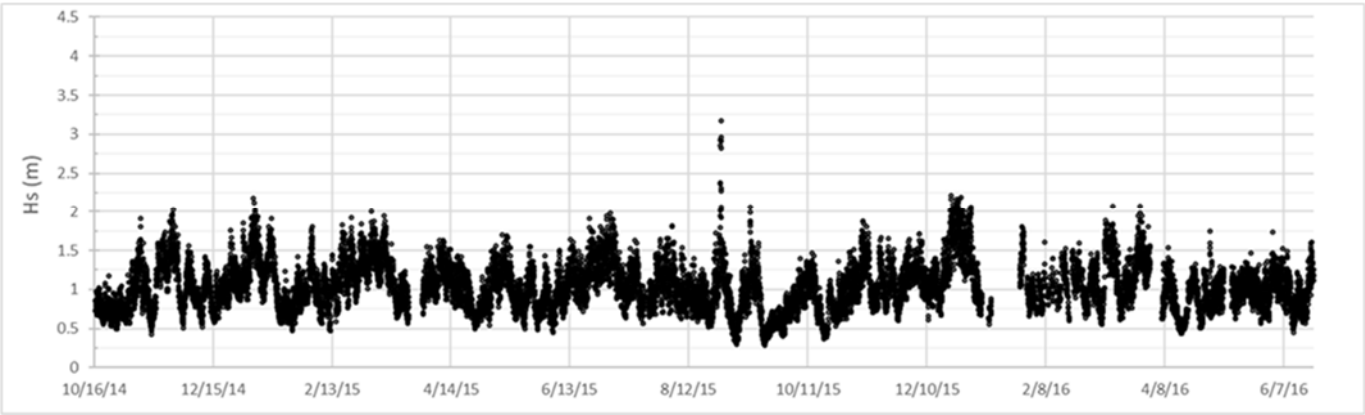

Figure I-8. Time history of Hs at AWAC-E.

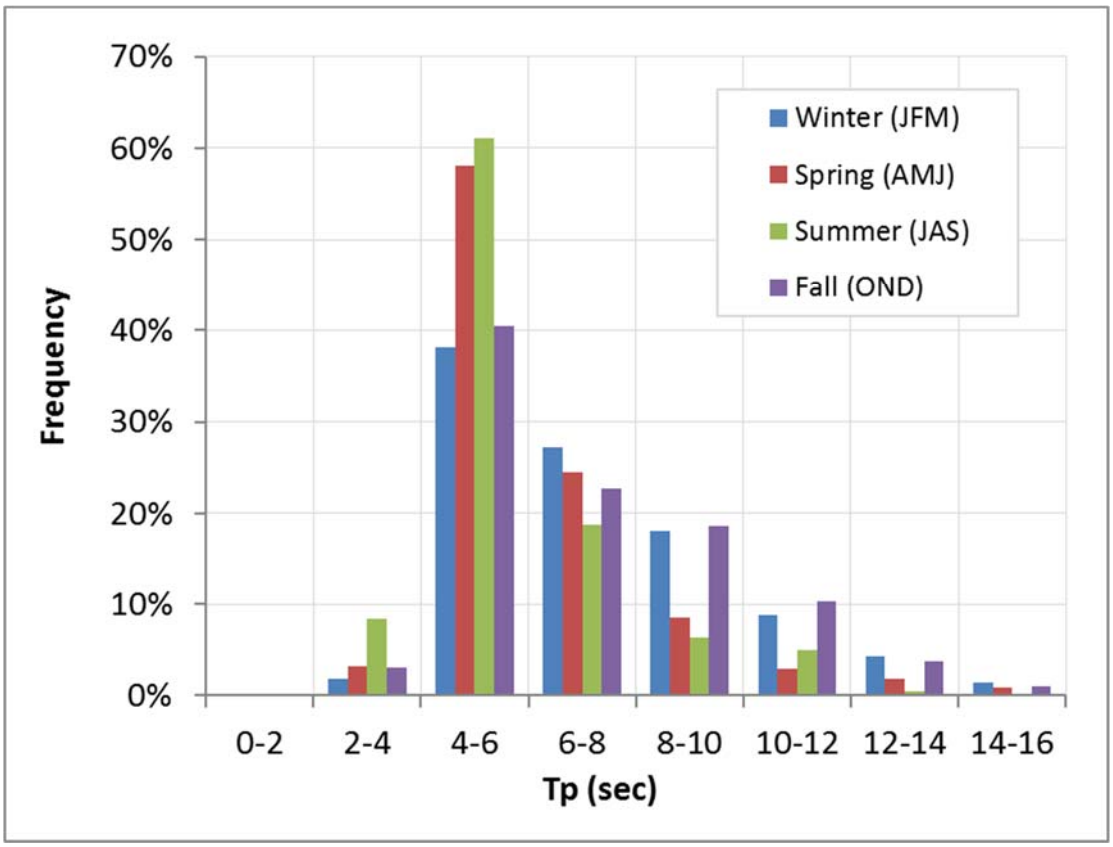

Figure I-9. Frequency of Tp at AWAC-E.

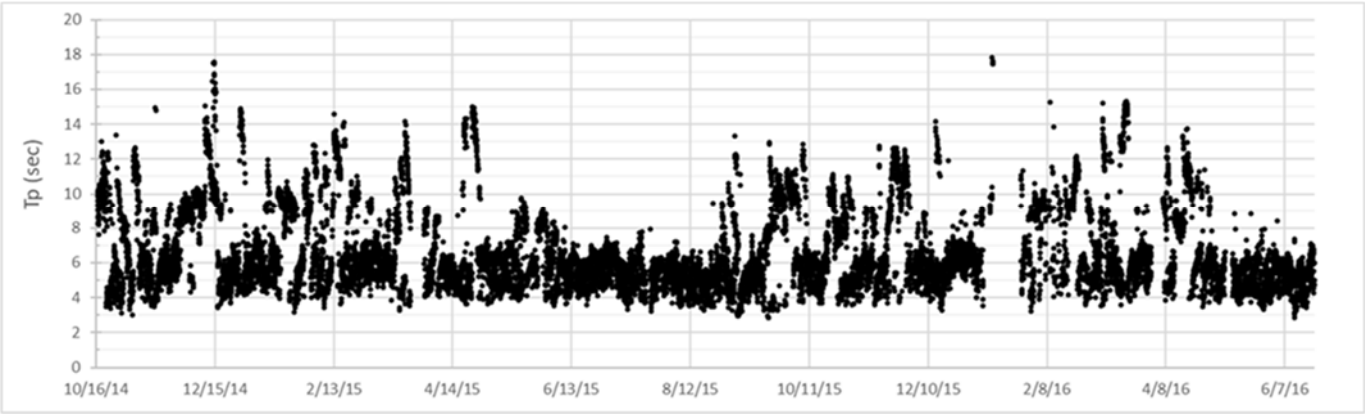

Figure I-10. Time history of Tp at AWAC-E.

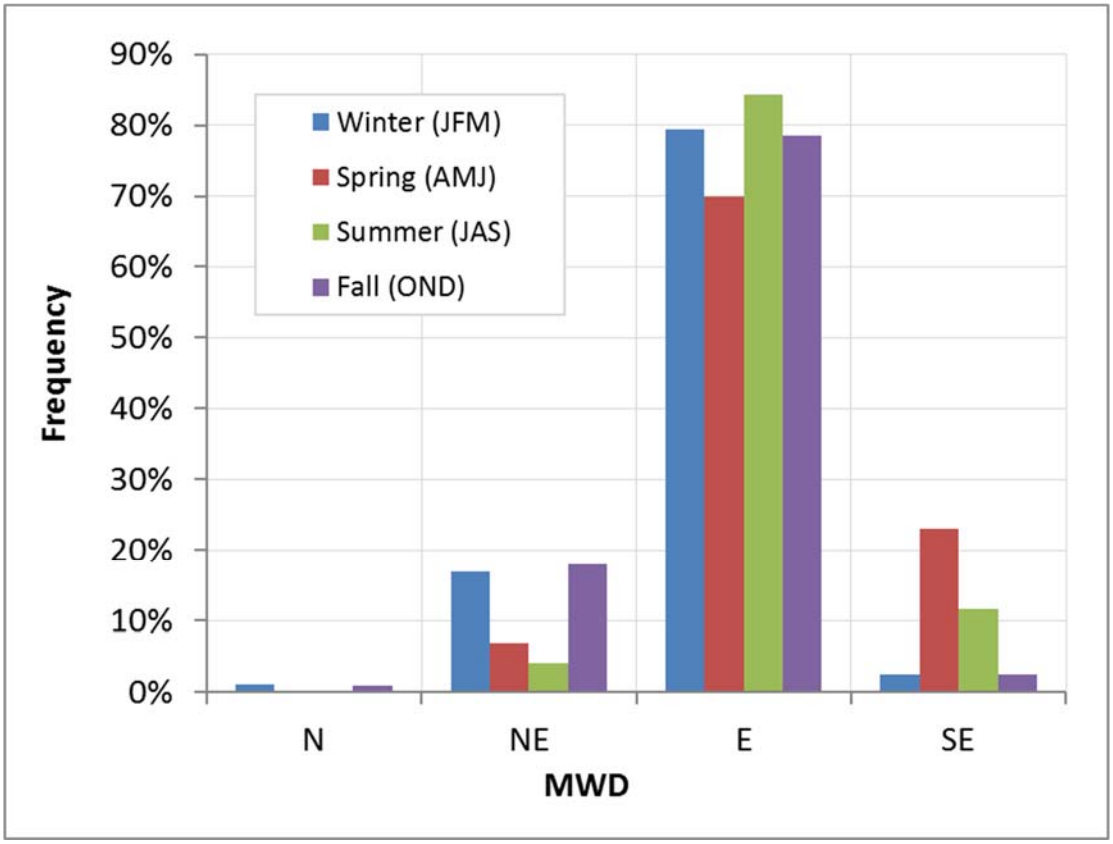

Figure I-11. Frequency of MWD at AWAC-E.

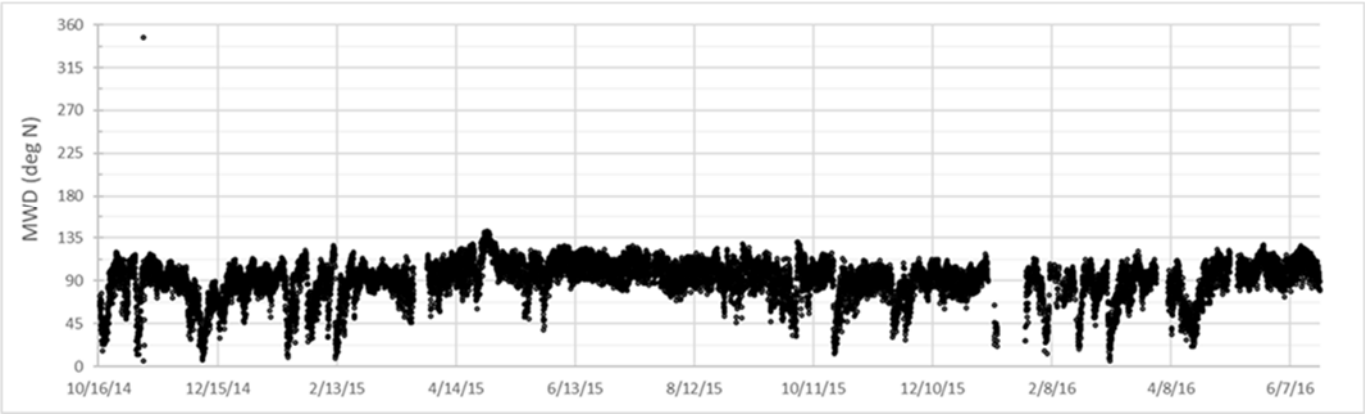

Figure I-12. Time history of MWD at AWAC-E.

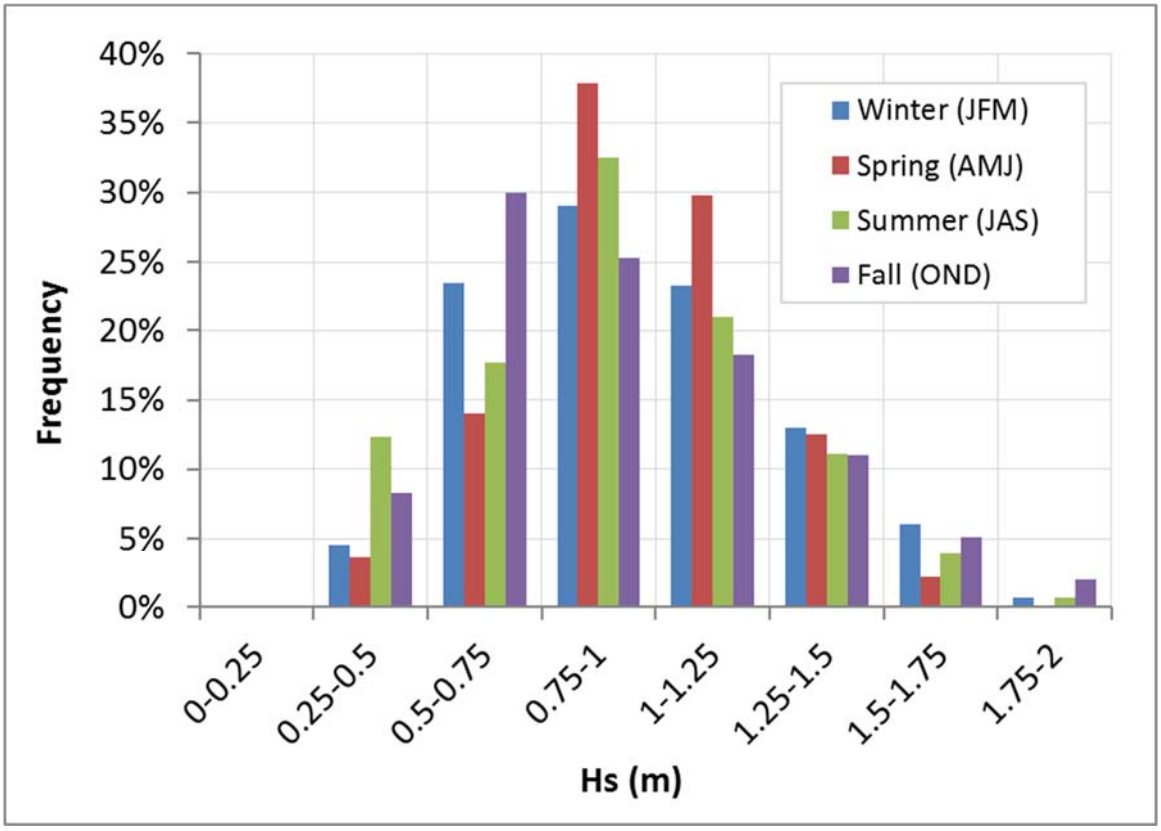

Figure I-13. Frequency of Hs at AWAC-S.

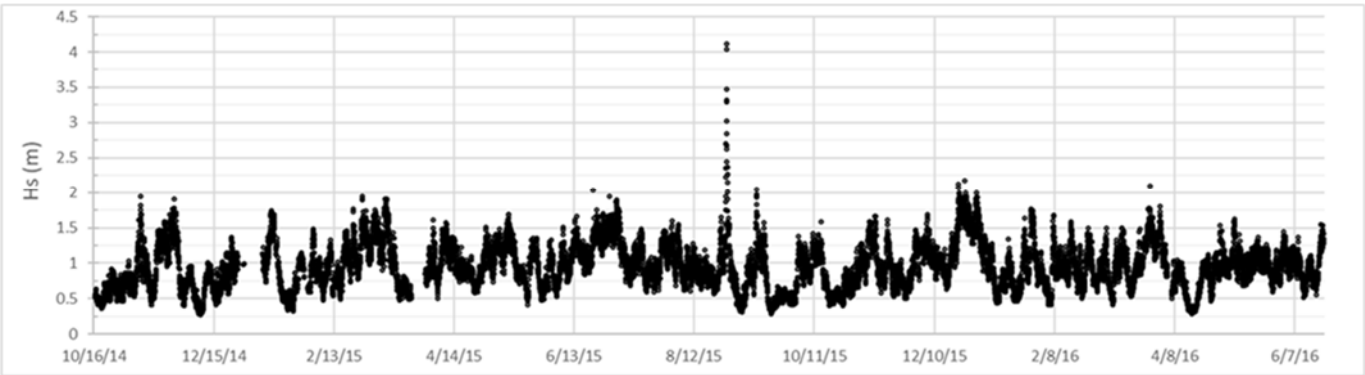

Figure I-14. Time history of Hs at AWAC-S.

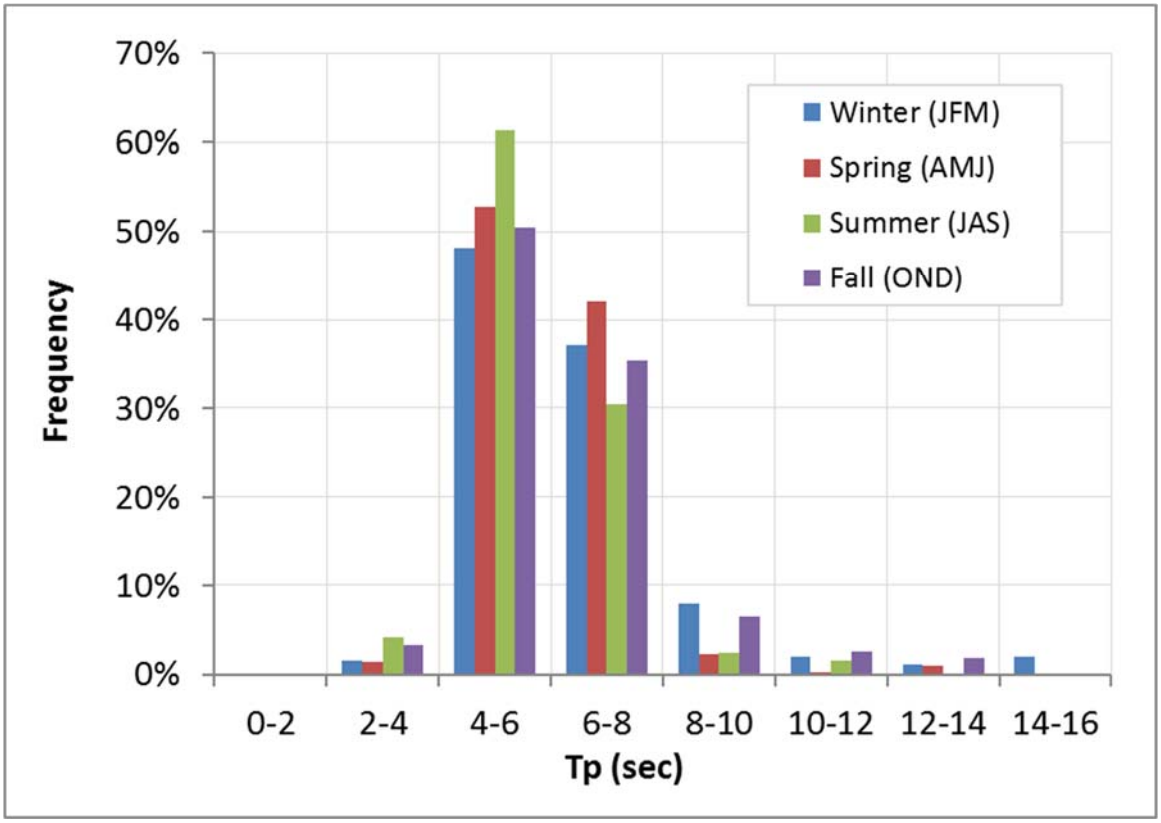

Figure I-15. Frequency of Tp at AWAC-S.

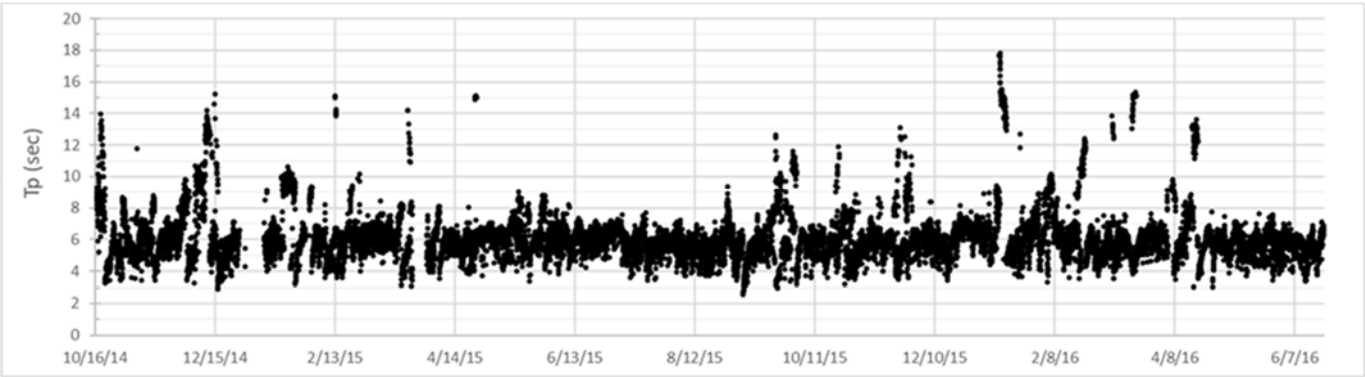

Figure I-16. Time history of Tp at AWAC-S.

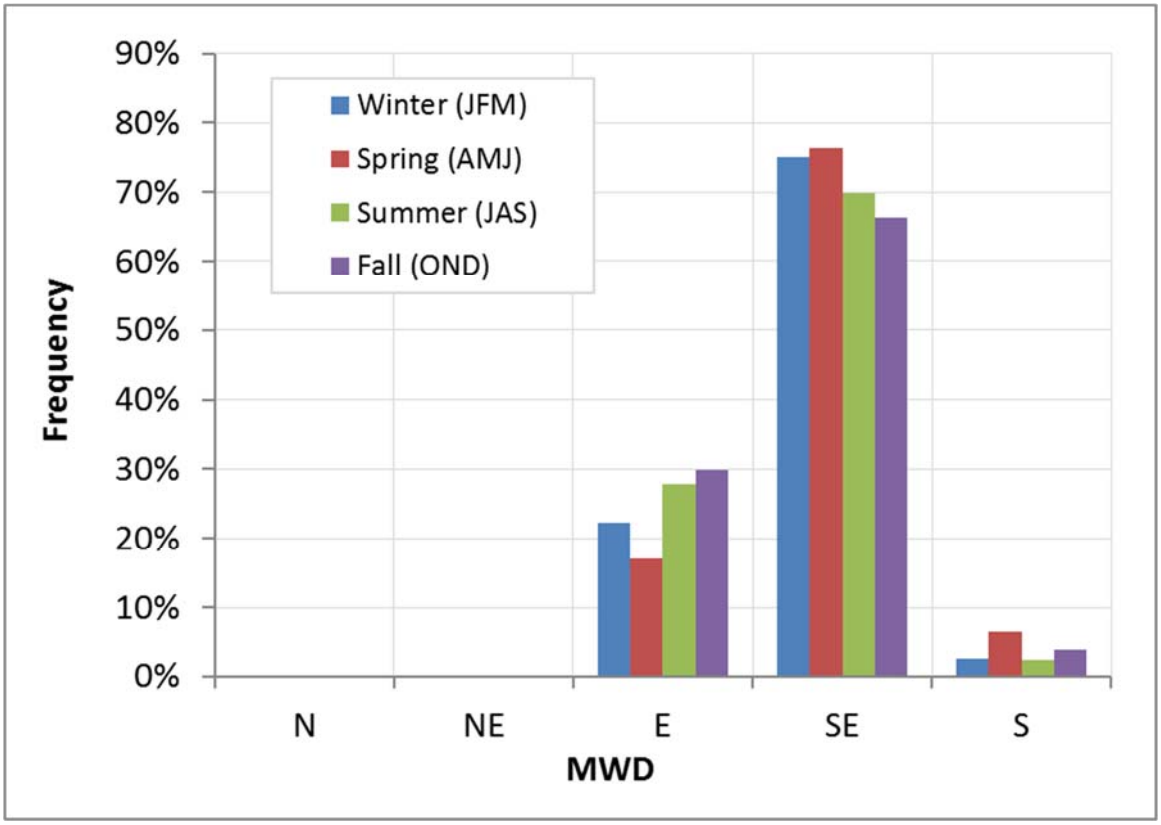

Figure I-17. Frequency of MWD at AWAC-S.

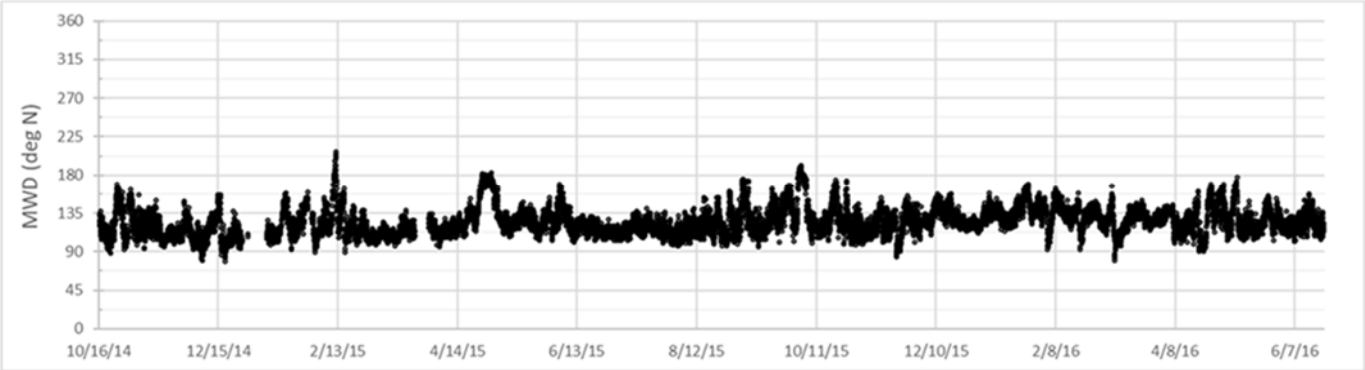

Figure I-18. Time history of MWD at AWAC-S.

Figure I-19. Location of NDBC Station 41043 NE Puerto Rico.

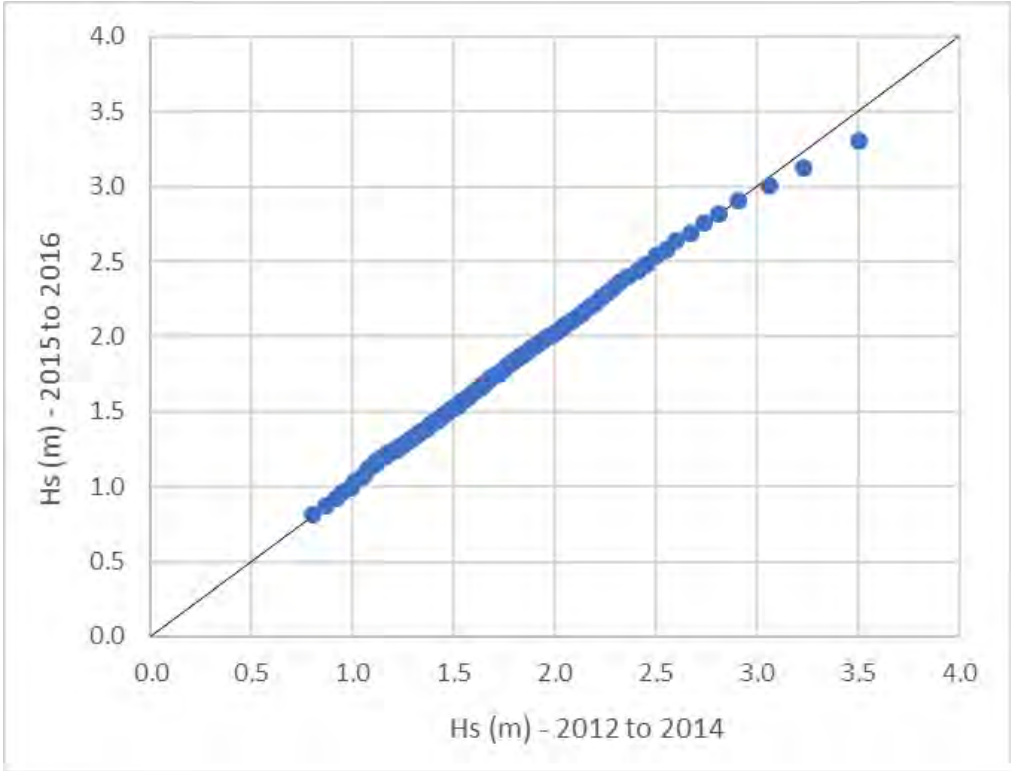

Figure I-20. Q-Q plot of Hs from 2105 to 2016 versus Hs from 2012 to 2014 at NDBC Station 41043 NE Puerto Rico.

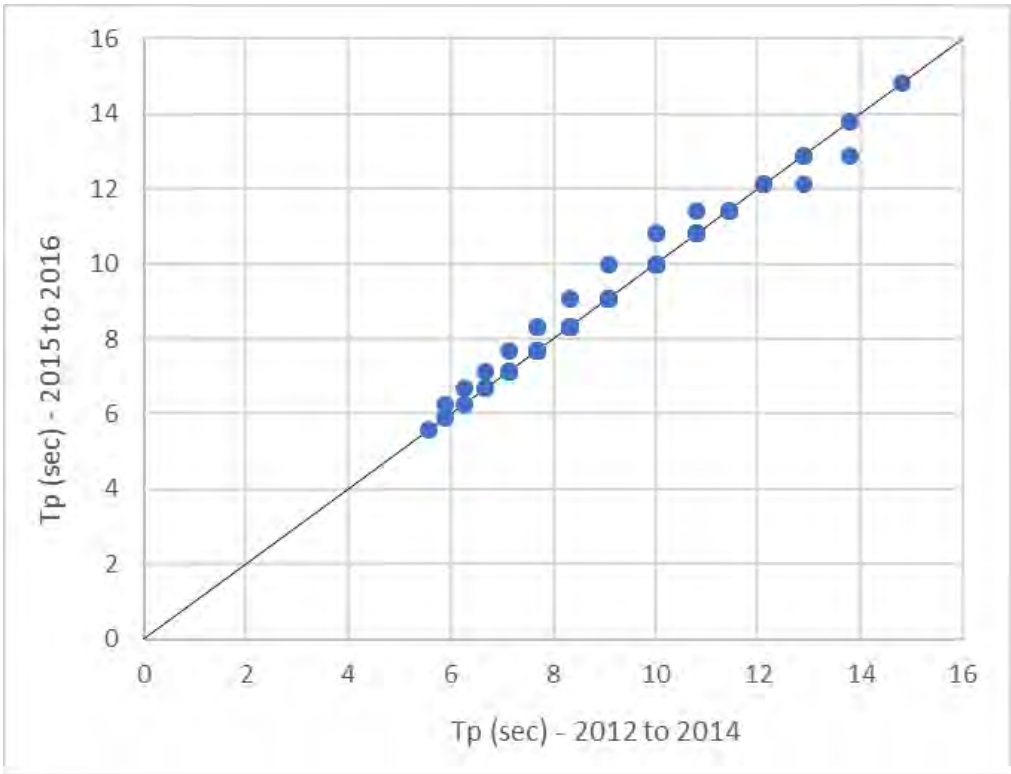

Figure I-21. Q-Q plot of Tp from 2105 to 2016 versus Tp from 2012 to 2014 at NDBC Station 41043 NE Puerto Rico.

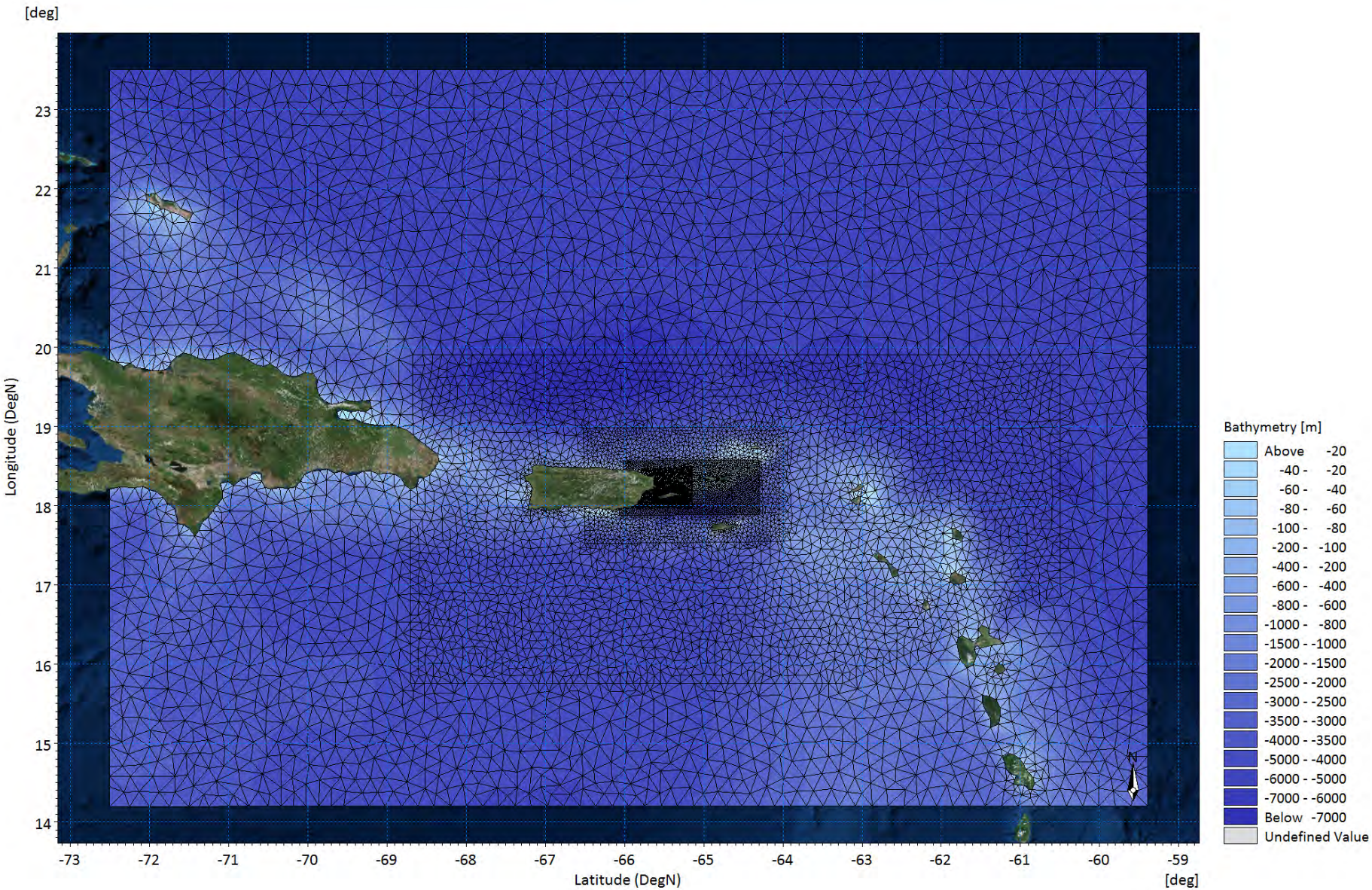

Figure I-22. Hurricane Maria model domain, mesh, and bathymetry.

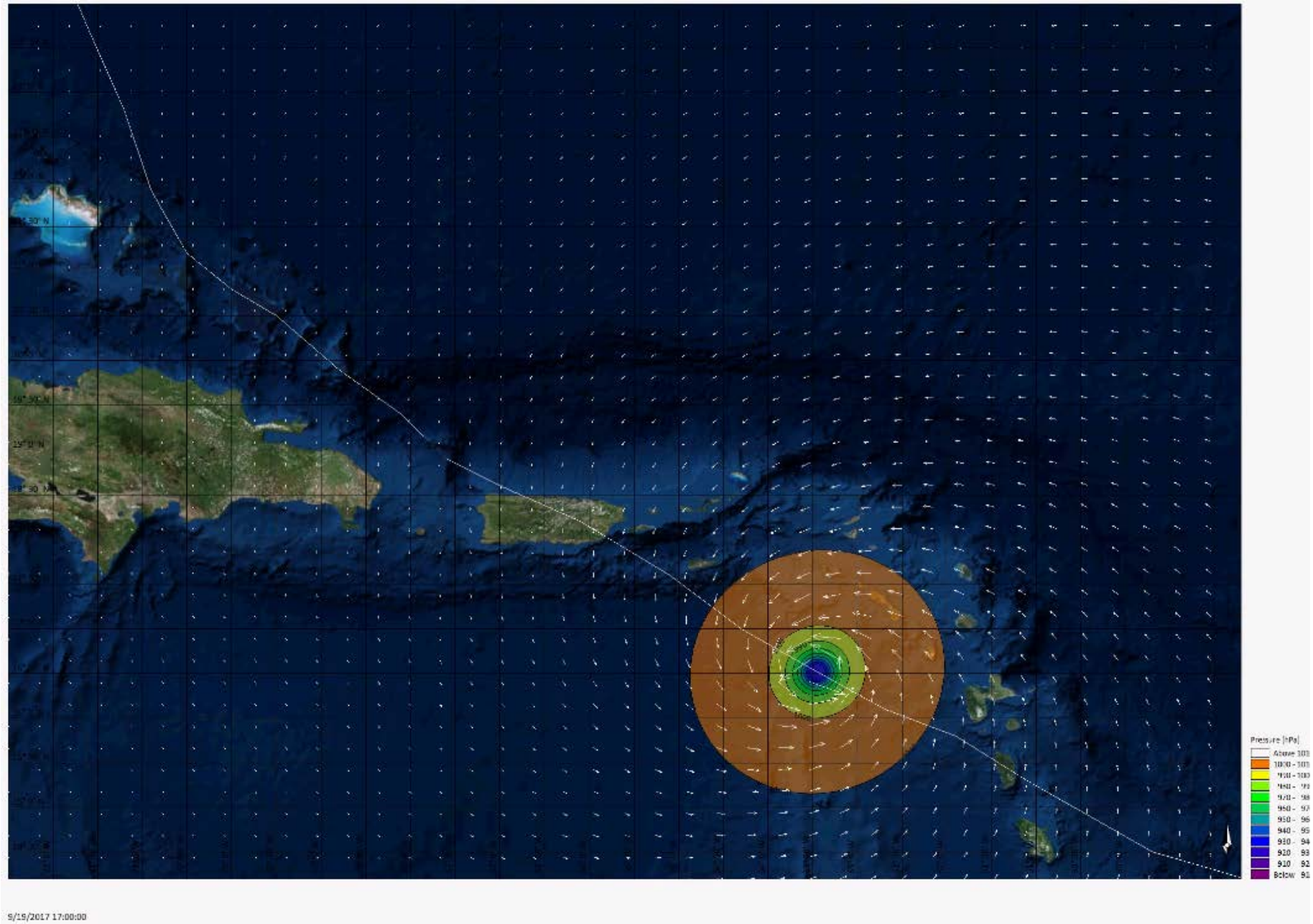

Figure I-23. Hurricane Maria track, and wind and pressure fields as it approaches Vieques.

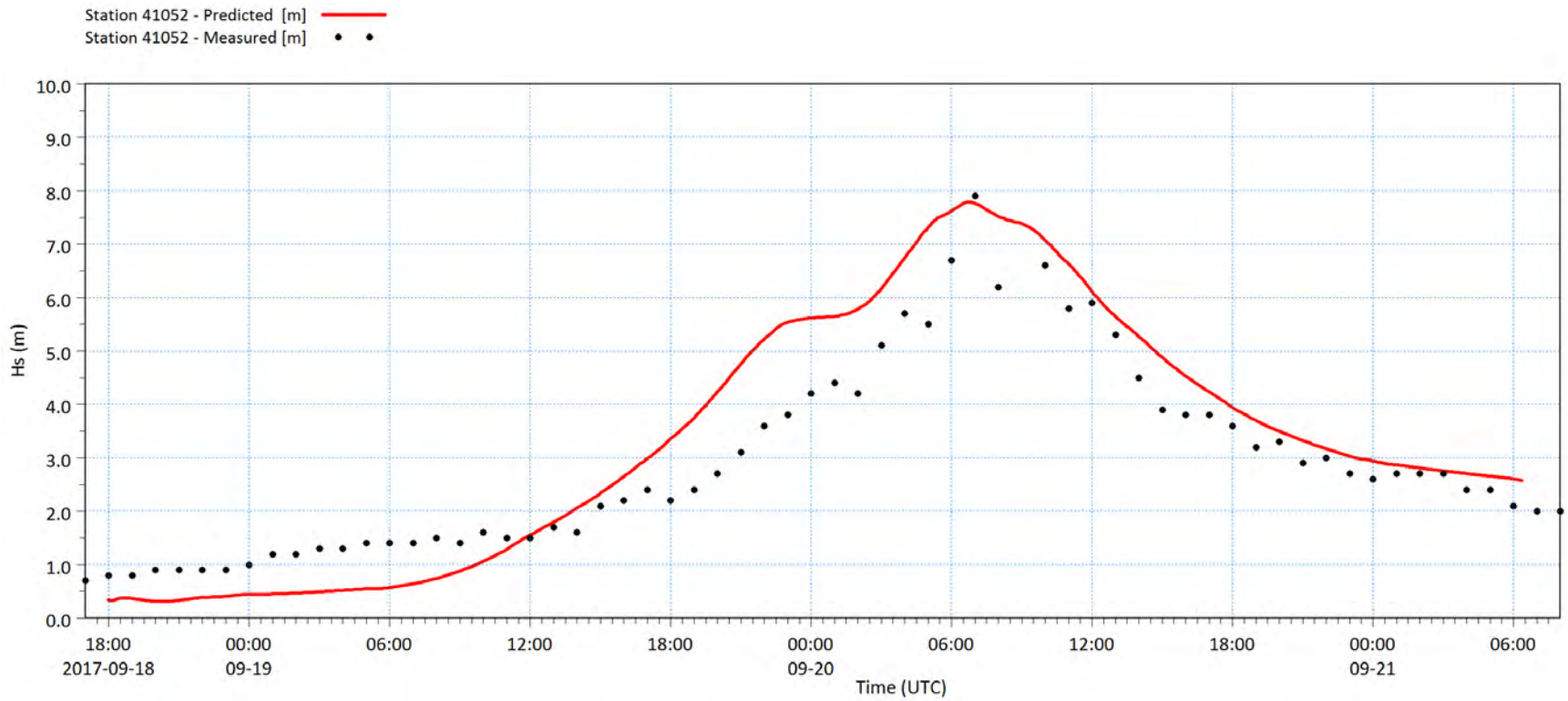

Figure I-24. Hurricane Maria measured and predicted significant wave heights at NDBC Station 41052 South of Saint John, VI.

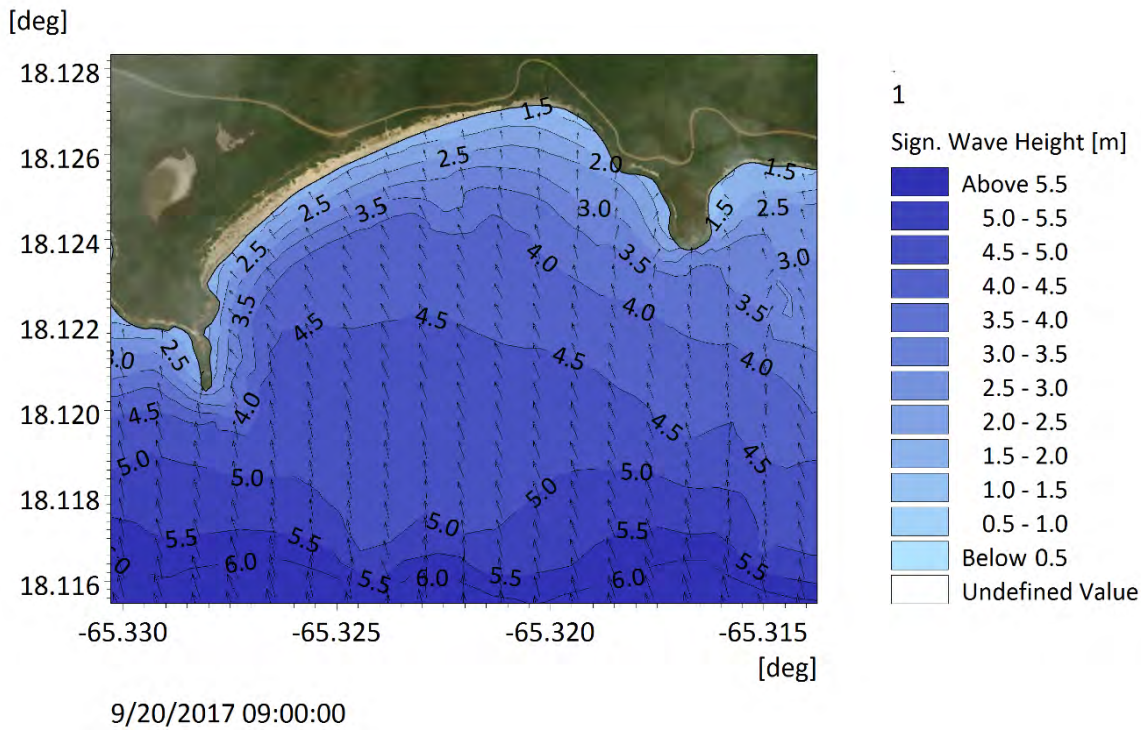

Figure I-25. Hs and MWD at the time of the highest waves at Beach 1 during Hurricane Maria.

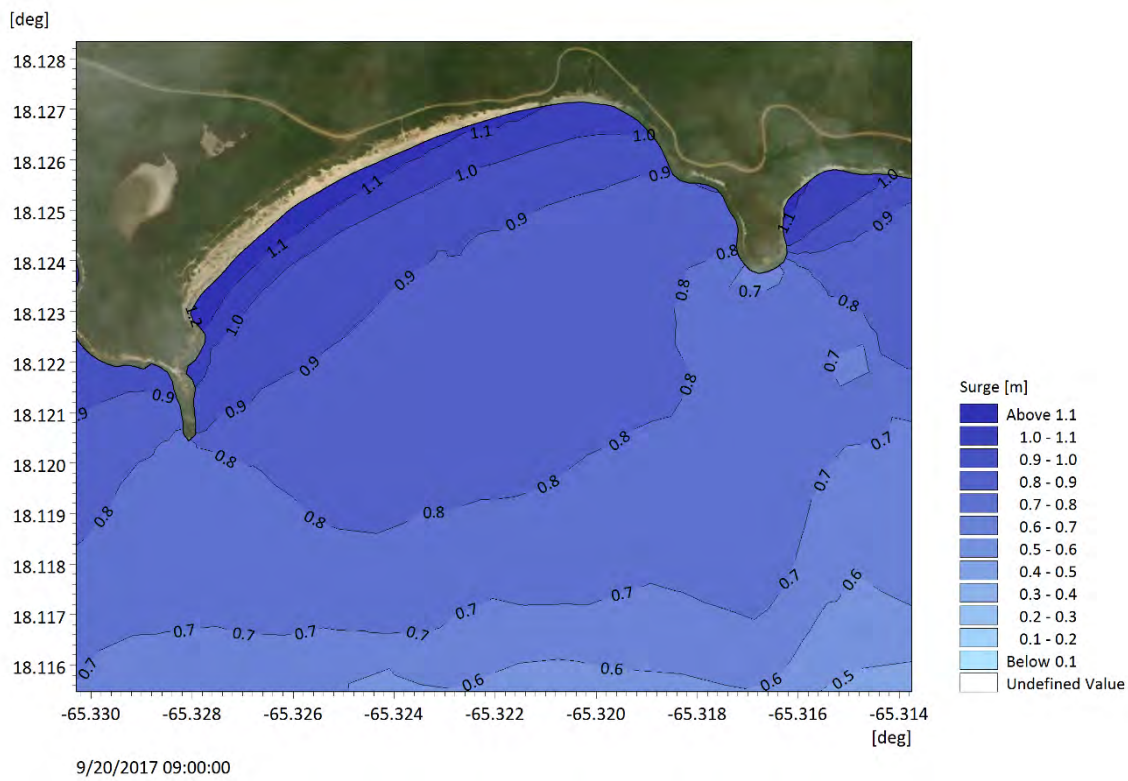

Figure I-26. Storm surge at the time of the highest waves at Beach 1 during Hurricane Maria.

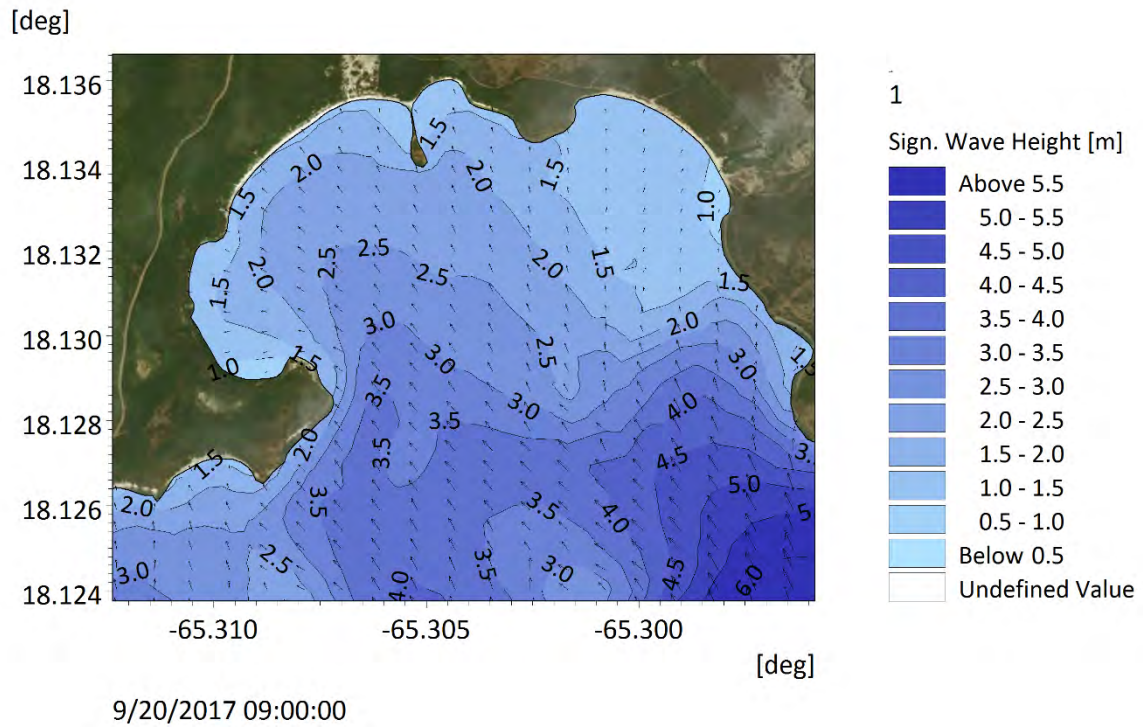

Figure I-27. Hs and MWD at the time of the highest waves at Beaches 2, 3 and 4 during Hurricane Maria.

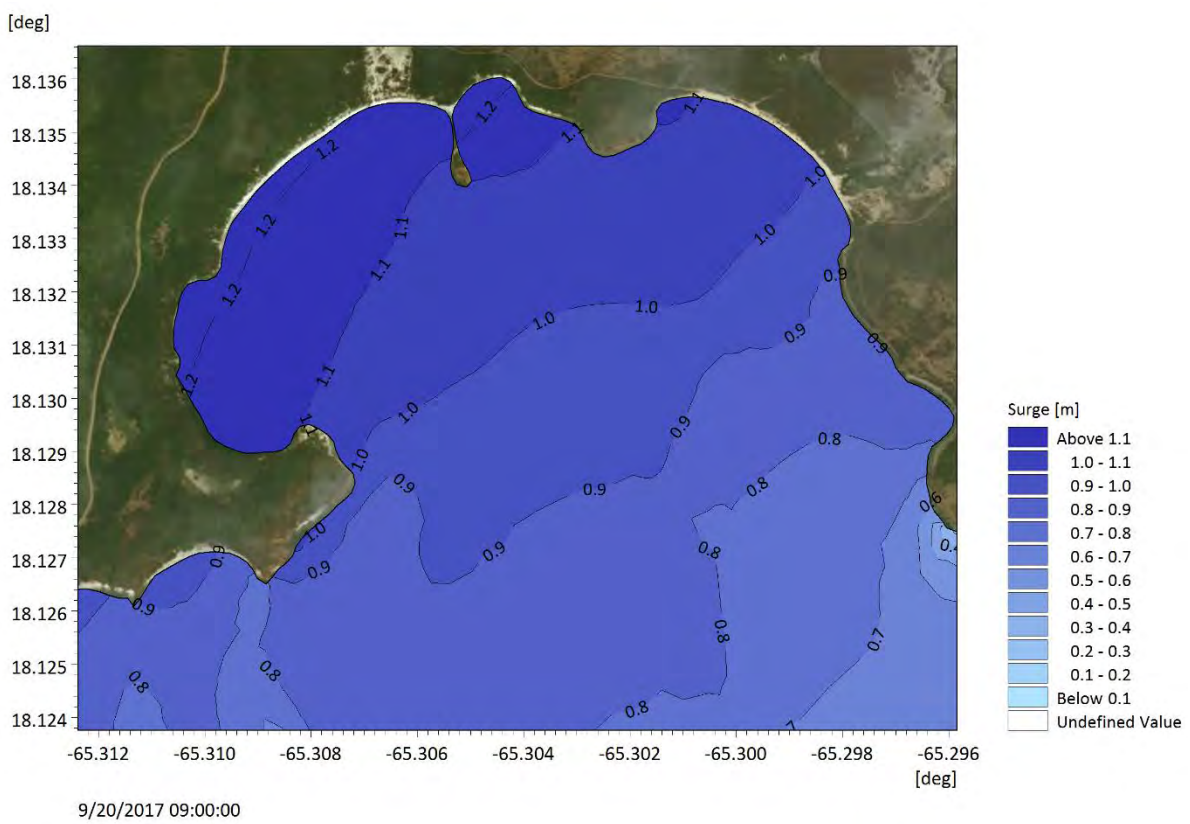

Figure I-28. Storm surge at the time of the highest waves at Beaches 2, 3 and 4 during Hurricane Maria.

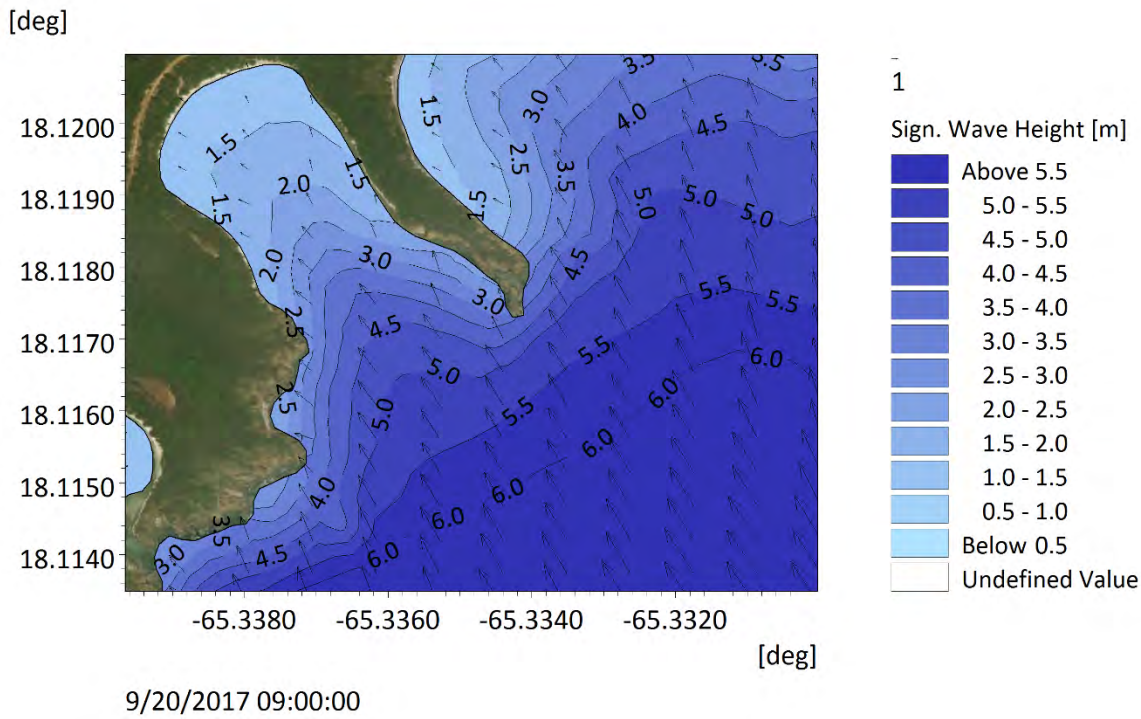

Figure I-29. Hs and MWD at the time of the highest waves at Beach 19 during Hurricane Maria.

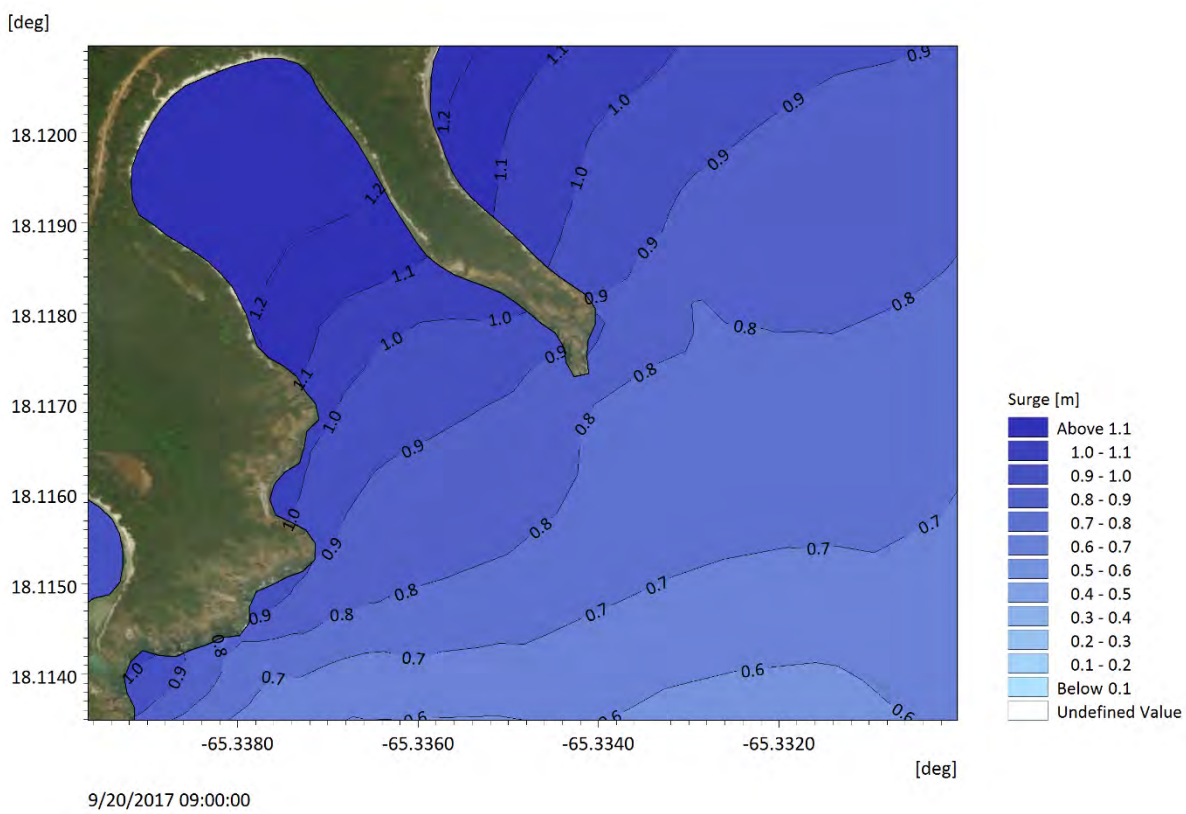

Figure I-30. Storm surge at the time of the highest waves at Beach 19 during Hurricane Maria.

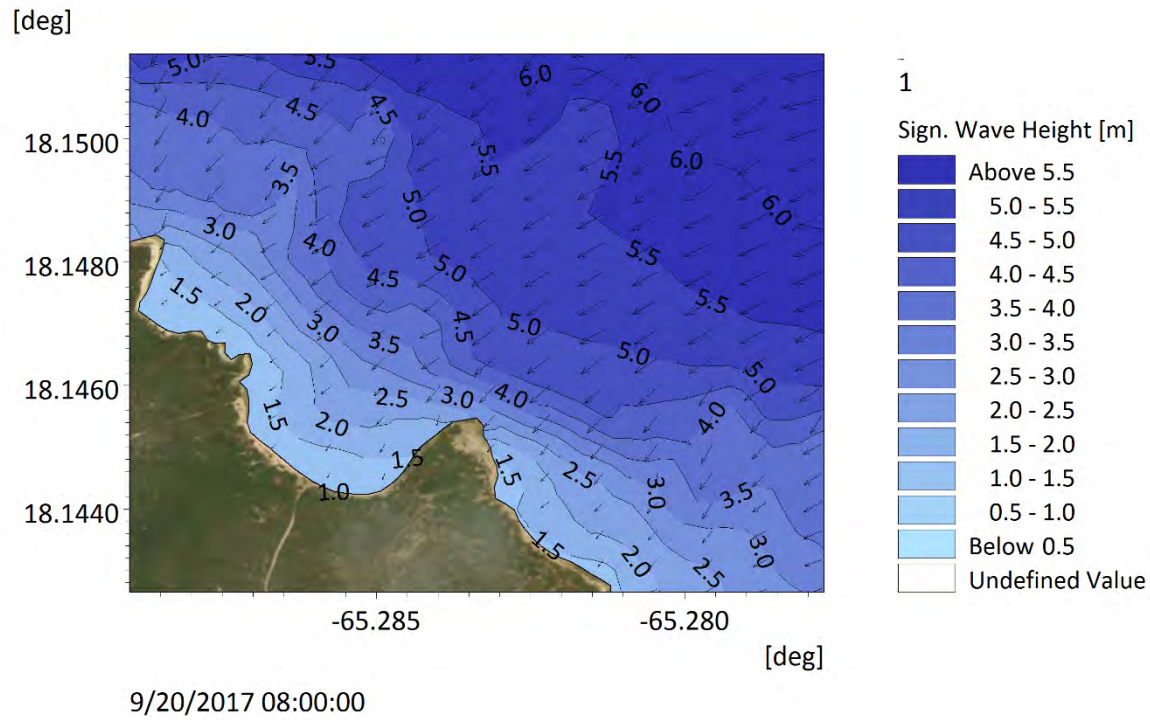

Figure I-31. Hs and MWD at the time of the highest waves at Beach 12 during Hurricane Maria.

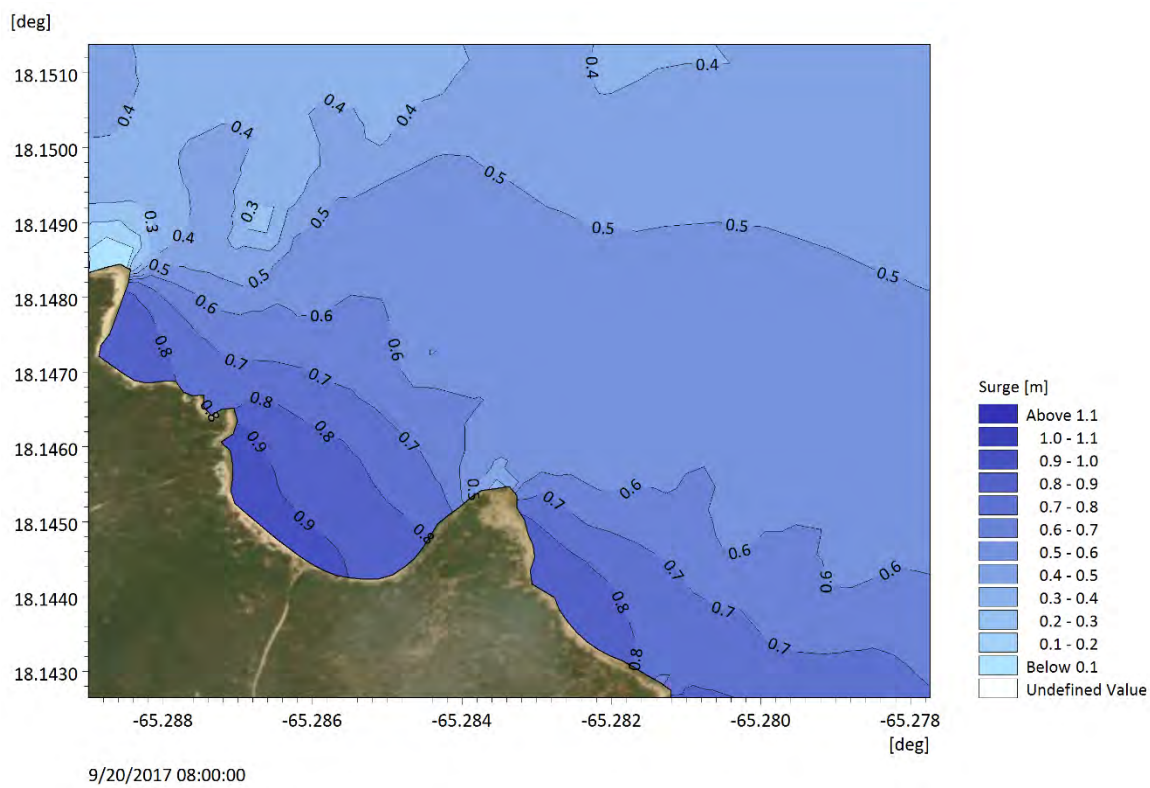

Figure I-32. Storm surge at the time of the highest waves at Beach 12 during Hurricane Maria.

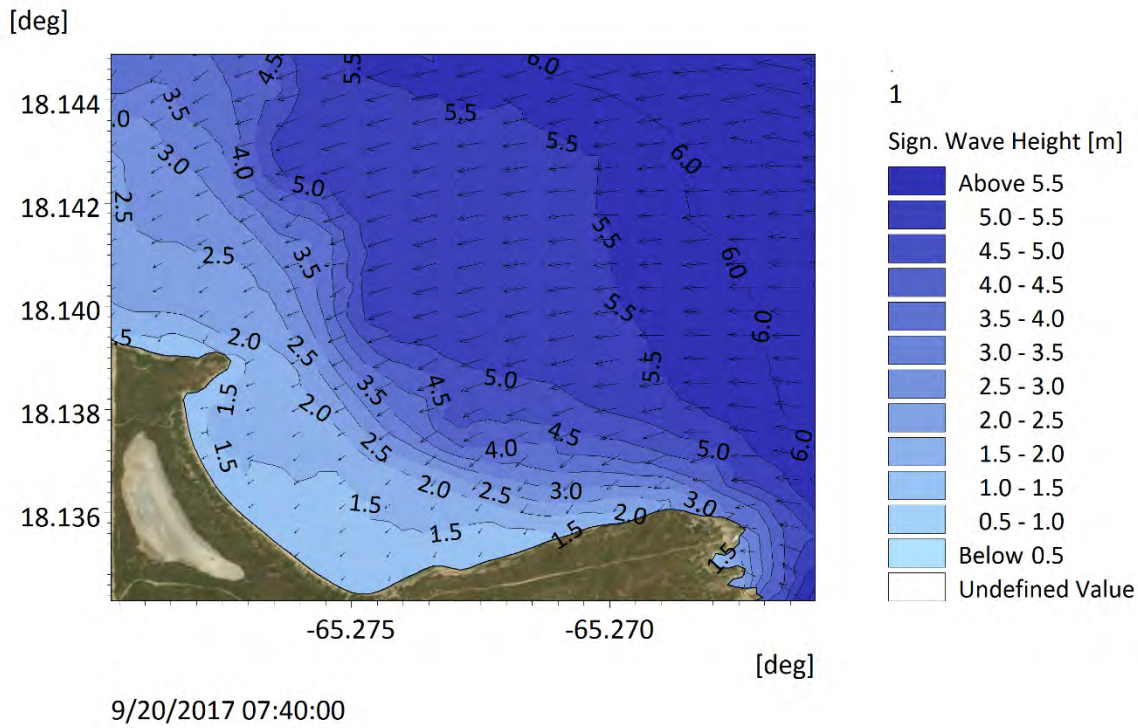

Figure I-33. Hs and MWD at the time of the highest waves at Beach 14 during Hurricane Maria.

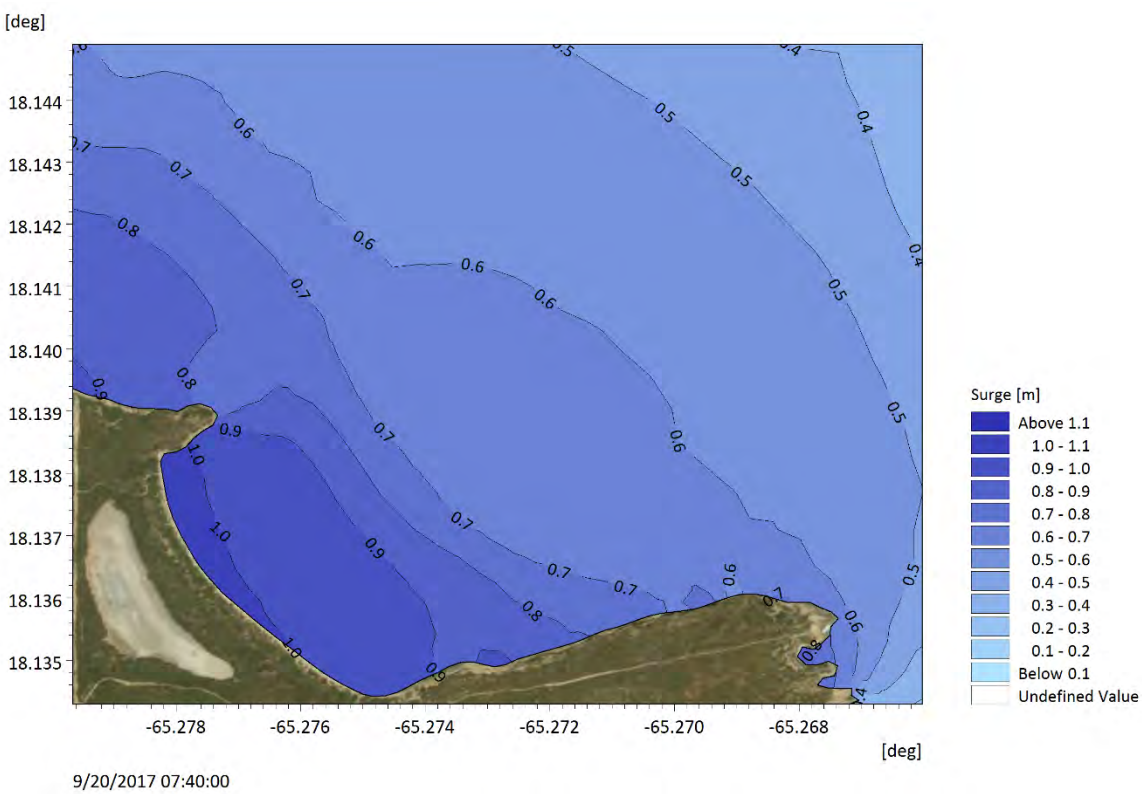

Figure I-34. Storm surge at the time of the highest waves at Beach 14 during Hurricane Maria.

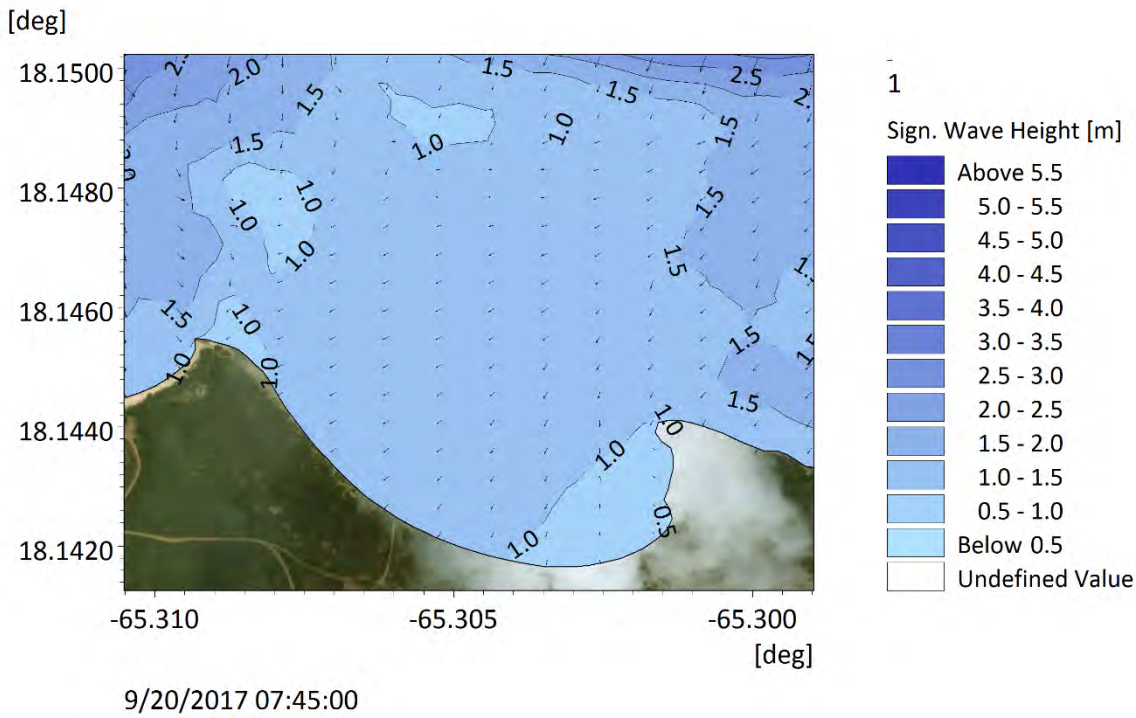

Figure I-35. Hs and MWD at the time of the highest waves at Beach 5 during Hurricane Maria.

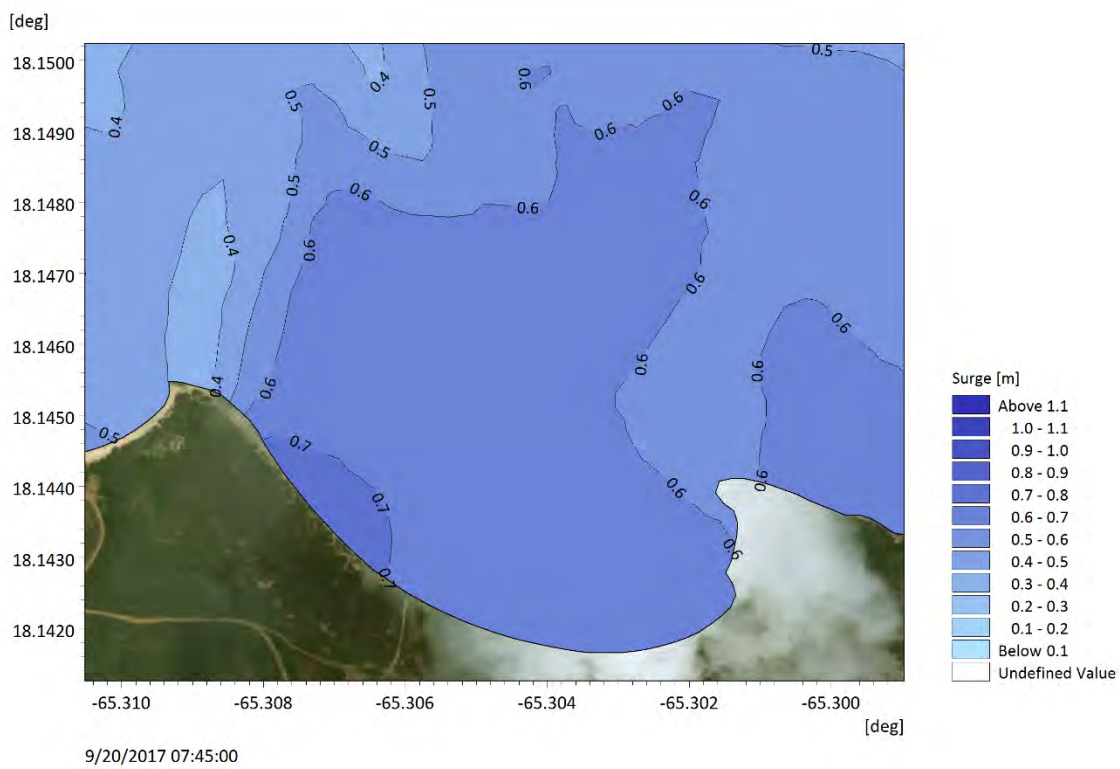

Figure I-36. Storm surge at the time of the highest waves at Beach 5 during Hurricane Maria.

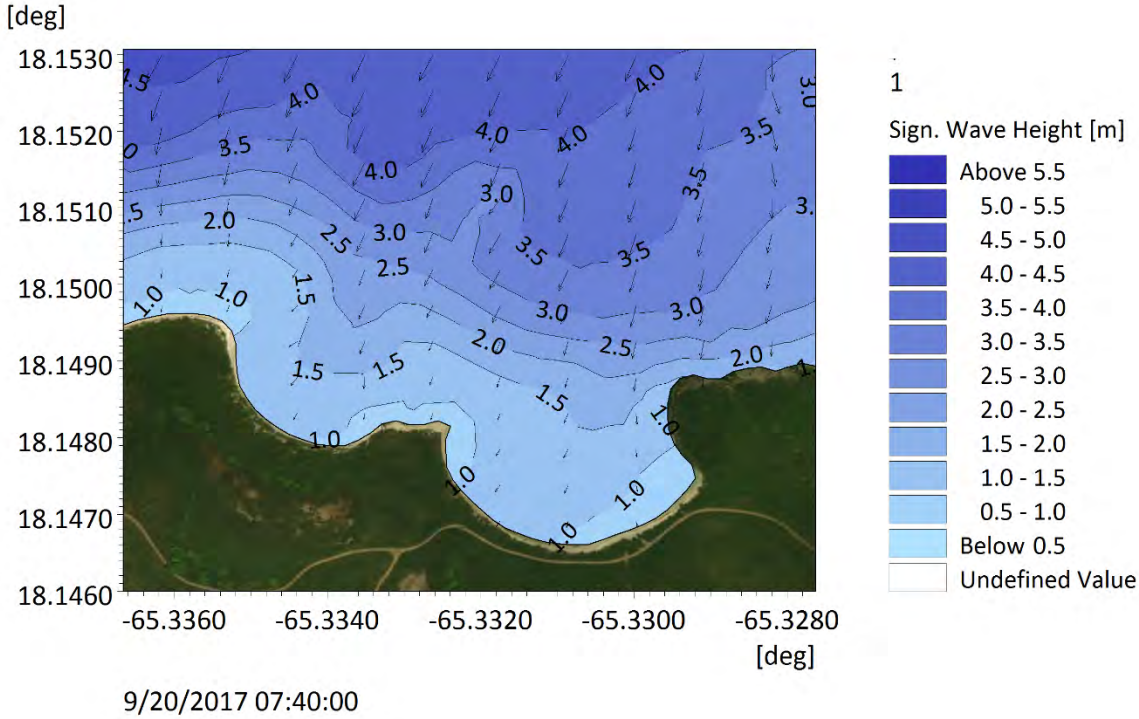

Figure I-37. Hs and MWD at the time of the highest waves at Beach 22 during Hurricane Maria.

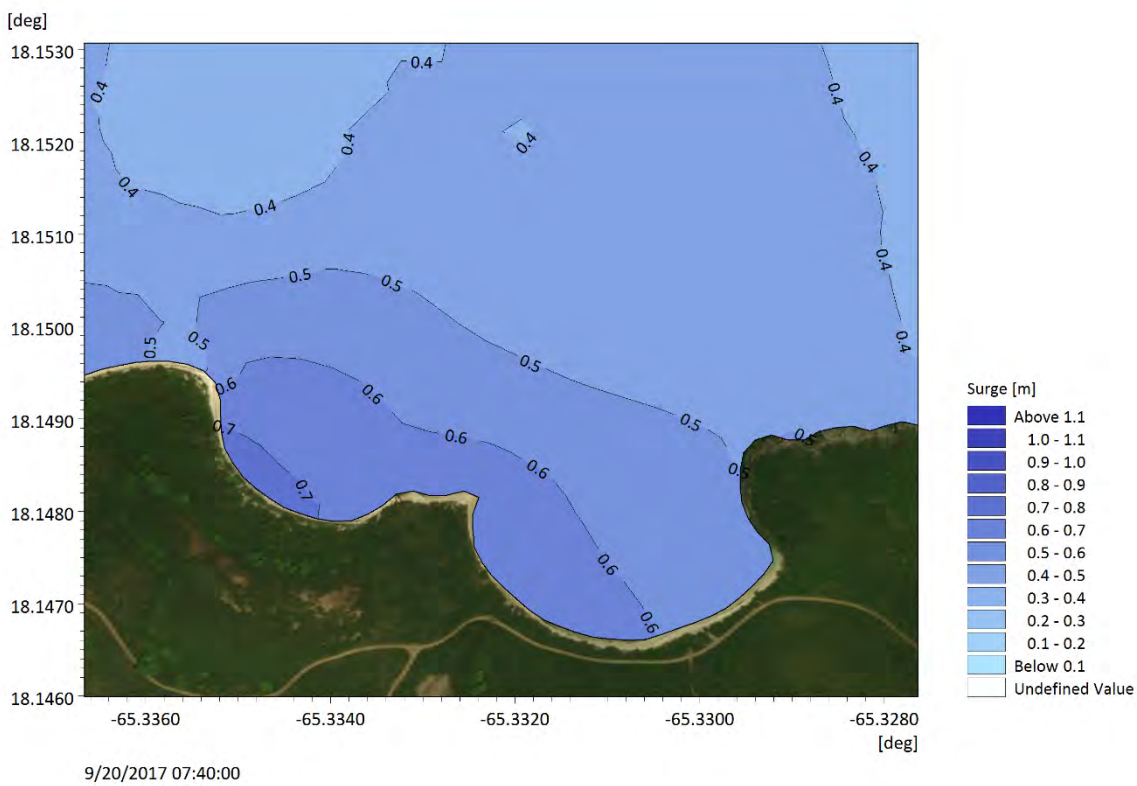

Figure I-38. Storm surge at the time of the highest waves at Beach 22 during Hurricane Maria.

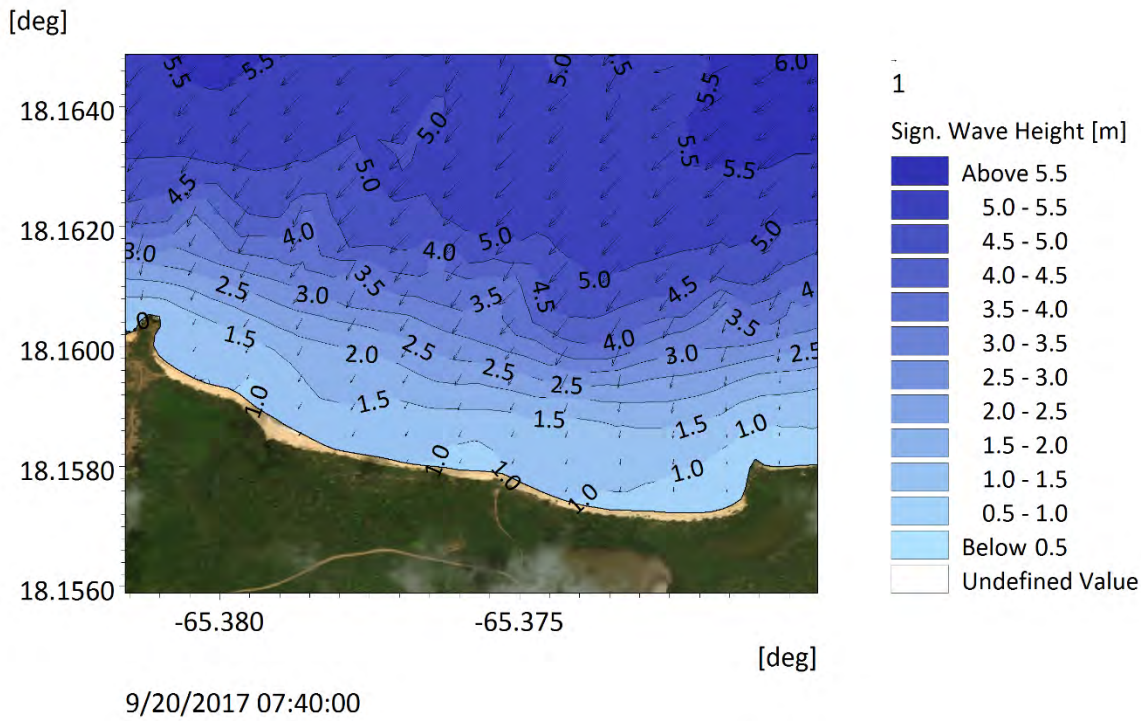

Figure I-39. Hs and MWD at the time of the highest waves at Beach 24 during Hurricane Maria.

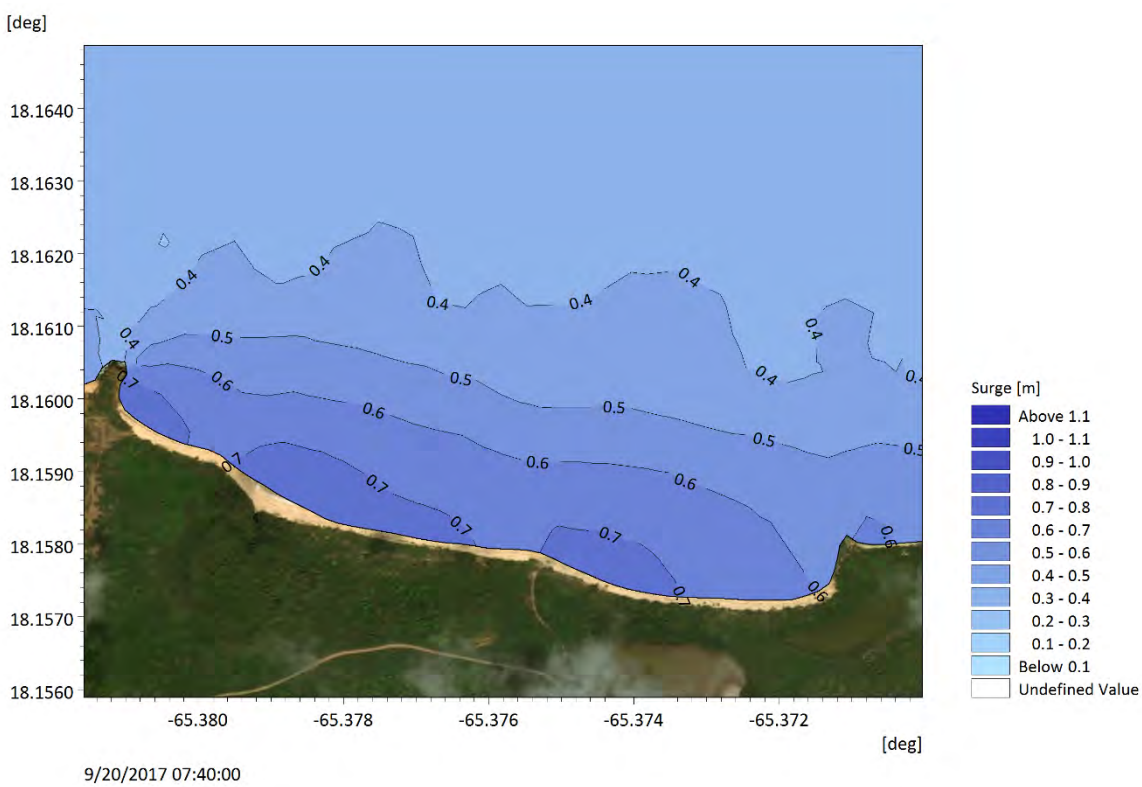

Figure I-40. Storm surge at the time of the highest waves at Beach 24 during Hurricane Maria.

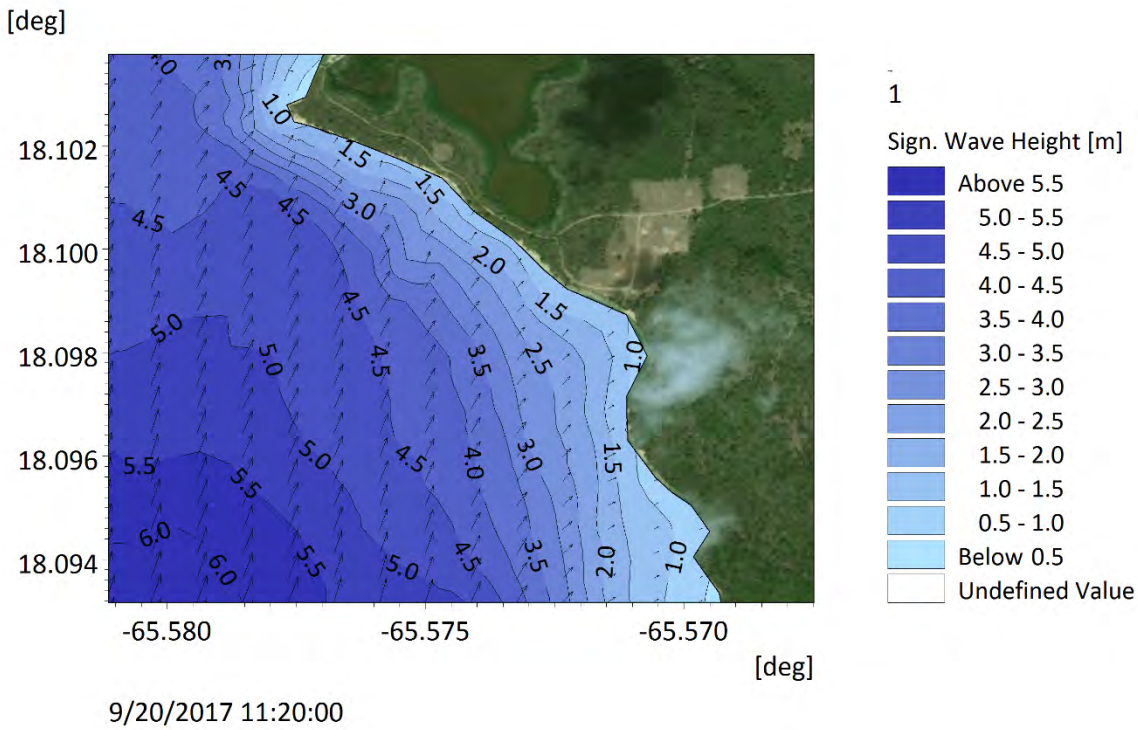

Figure I-41. Hs and MWD at the time of the highest waves at SWMU 4 (southwest-facing) during Hurricane Maria.

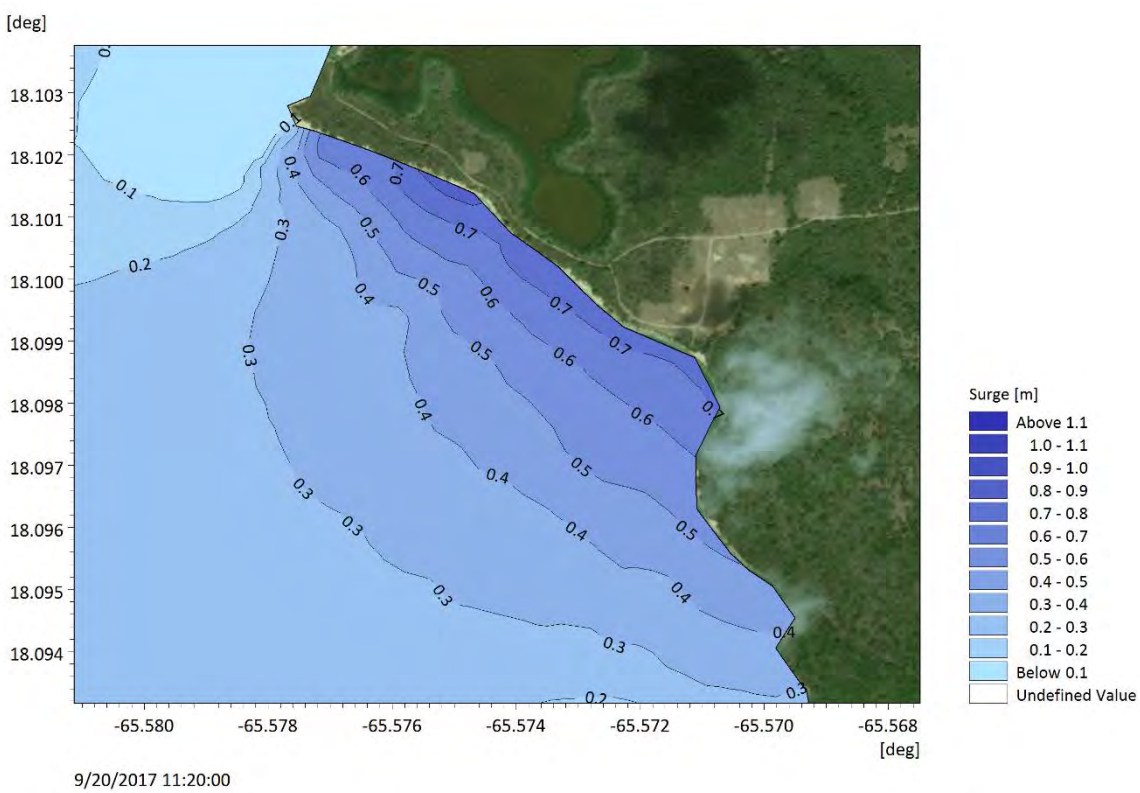

Figure I-42. Storm surge at the time of the highest waves at SWMU 4 (southwest-facing) during Hurricane Maria.

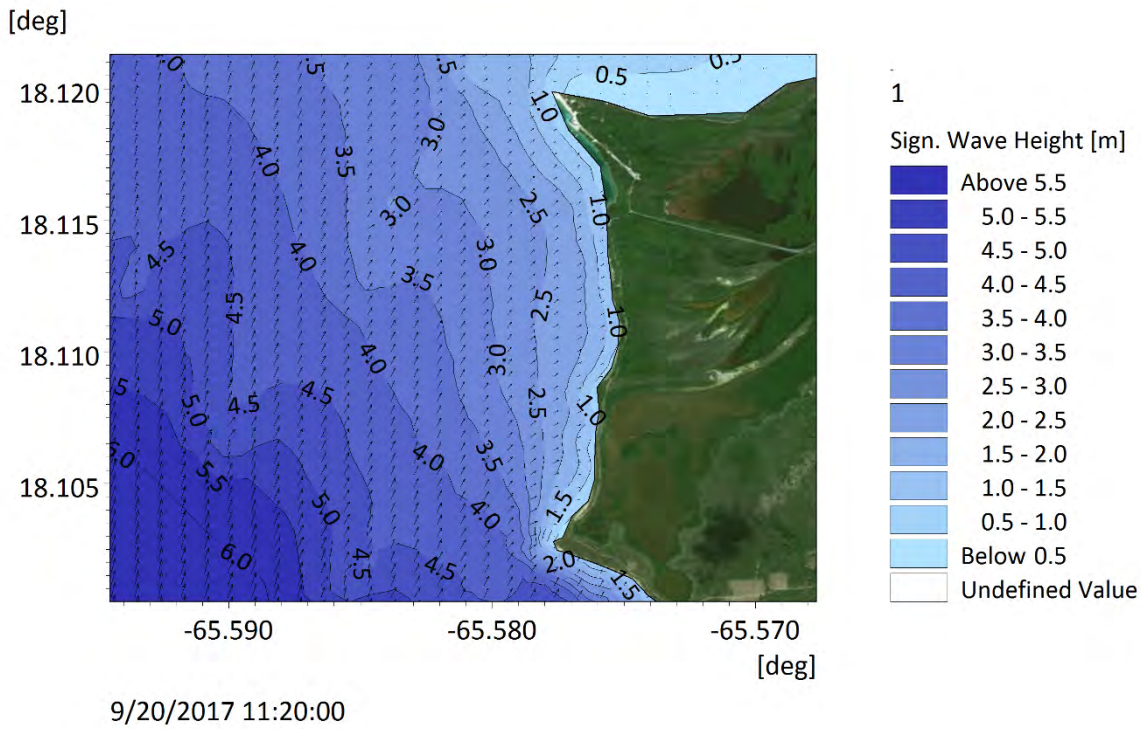

Figure I-43. Hs and MWD at the time of the highest waves at SWUM 4 (west-facing) during Hurricane Maria.

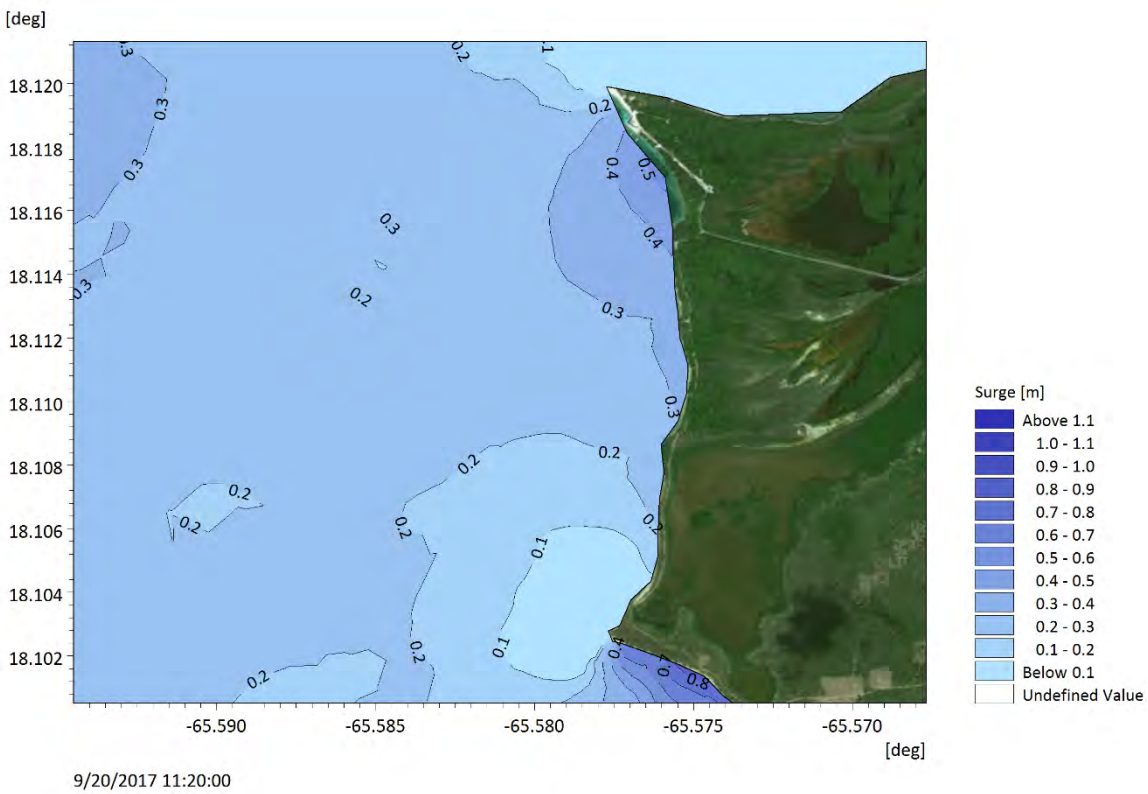

Figure I-44. Storm surge at the time of the highest waves at SWUM 4 (west-facing) during Hurricane Maria.

Appendix J
Beach Dynamics Results and Analysis

Appendix J

Beach Dynamics Results and Analysis

This Appendix describes the Beach Dynamics Investigation (BDI) results and analyses for:

- Live Impact Area (LIA) UXO 2 Beaches 2, 3, 4, 5, 12, and 14
- North Eastern Maneuver Area (EMA) and Surface Impact Area (SIA) UXO 7 Beaches 22 and 24
- South SIA UXO 8 Beaches 1 and 19
- Solid Waste Management Unit (SWMU) 4

For each beach, the following is included:

- Aerial view of transects, bathymetry, and coastal features where the 1 meter (m) water depth contours are provided only to represent the general features of the bathymetry fronting the beaches (e.g. shallow and deep areas, gentle and steep slopes, etc.). The water depth contours were derived from hydrographic surveys performed in the year 2000 by JALBCTX/USACE, about 15 years before the CH2M BDI (2014). While the bathymetry fronting the beaches in Vieques is not expected to exhibit significant changes, discrepancies between the BDI surveys and those by JALBCTX/USACE should be expected. To avoid confusion, the water depth contours are not labeled.
- For each beach transect, plots of:
  - Envelope of beach profiles measured during the BDI (BDI high and BDI low), elevation (meters [m], Puerto Rico Vertical Datum 2002 [PRVD02]) versus cross-shore distance (m from transect head)
  - Location of the depth of closure
  - Post-Hurricane Maria beach profile surveyed between October 30 and November 7, 2017
  - Where applicable, a plot with a close up of the depth of closure is included
- A table listing, for each transect:
  - The location of, and the depth of closure
  - Landward limit of beach change, and elevation, derived from the BDI surveys
  - Landward limit of beach change, and elevation, derived from the post-Maria surveys between October 30 and November 7, 2017
  - Width of the area of beach change derived from the analysis of the beach profiles and aerial photos, resulting from the wave and water level conditions during the BDI and Hurricane Maria
- A table listing, for each transect, the location of maximum elevation change, range, and elevation of the high and low envelope relative to PRVD02
- Plan view of approximate locations of the sediment samples taken during the BDI, BDI landward limit of beach change, maximum landward and seaward shoreline positions during the BDI, depth of closure
- Distribution of sediment size at each sampling location through time and in the cross-shore direction

References

CH2M HILL, Inc. (CH2M). 2014. *Quality Assurance Project Plan Beach Dynamics Investigation Eleven Beaches at the Former Vieques Naval Training Range (VNTR) and the Former Naval Ammunition Support Detachment (NASD), Atlantic Fleet Weapons Training Area – Vieques, Vieques, Puerto Rico*. February.

LIA UXO 2
Beach 2

Figure J-1. Beach 2 transects, bathymetry, and coastal features.

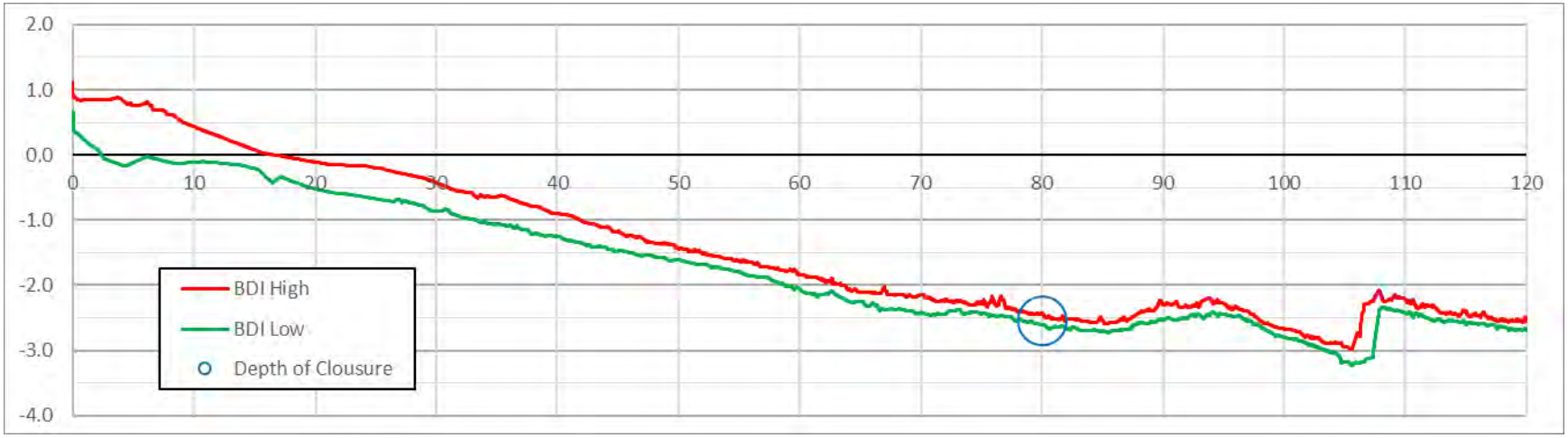

Figure J-2. Envelope of beach profiles and depth of closure at Beach 2 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

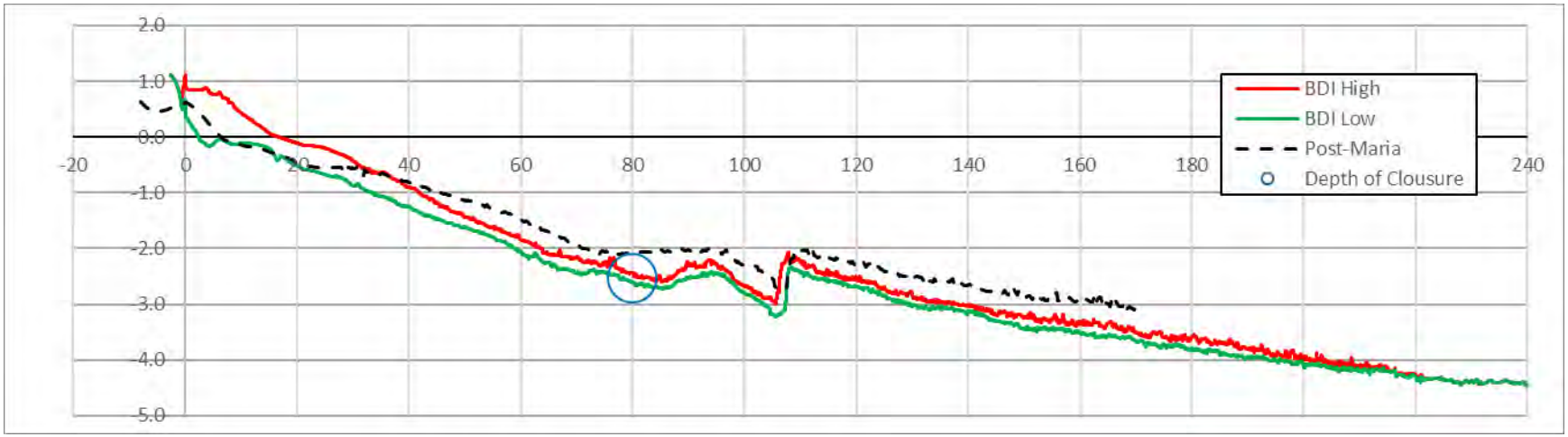

Figure J-3. Envelope of beach profiles, post-Maria profile, and depth of closure at Beach 2 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

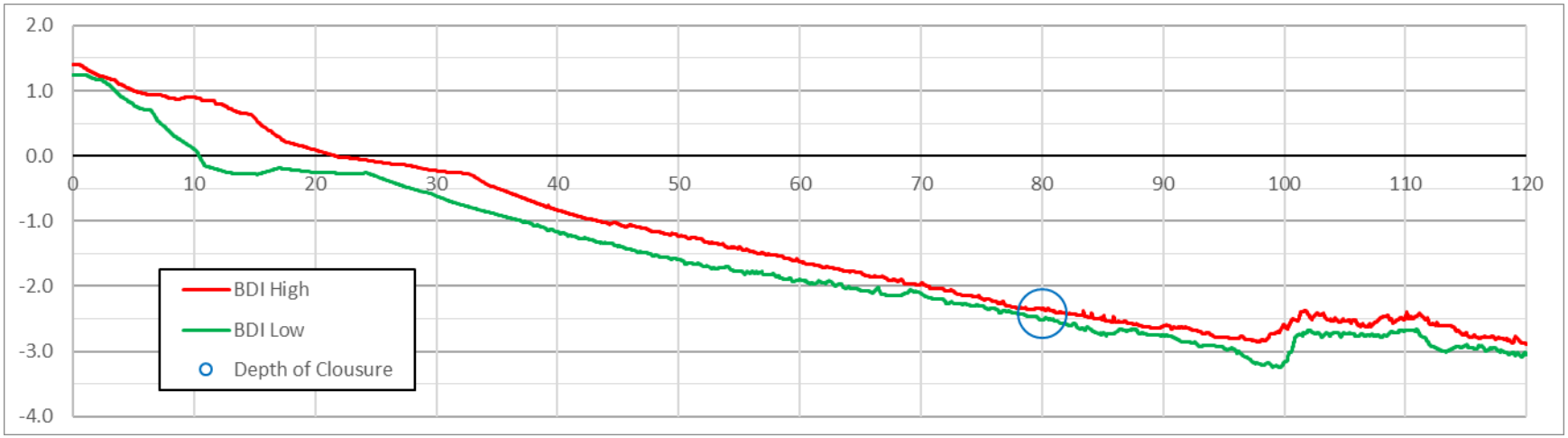

Figure J-4. Envelope of beach profiles Beach 2 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

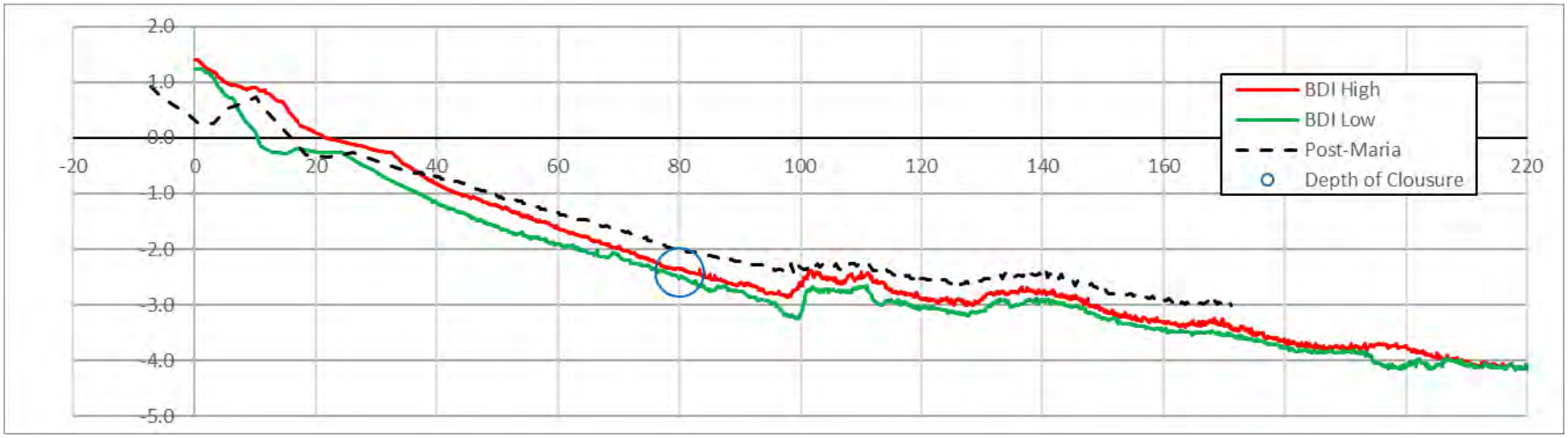

Figure J-5. Envelope of beach profiles, post-Maria profile, and depth of closure at Beach 2 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

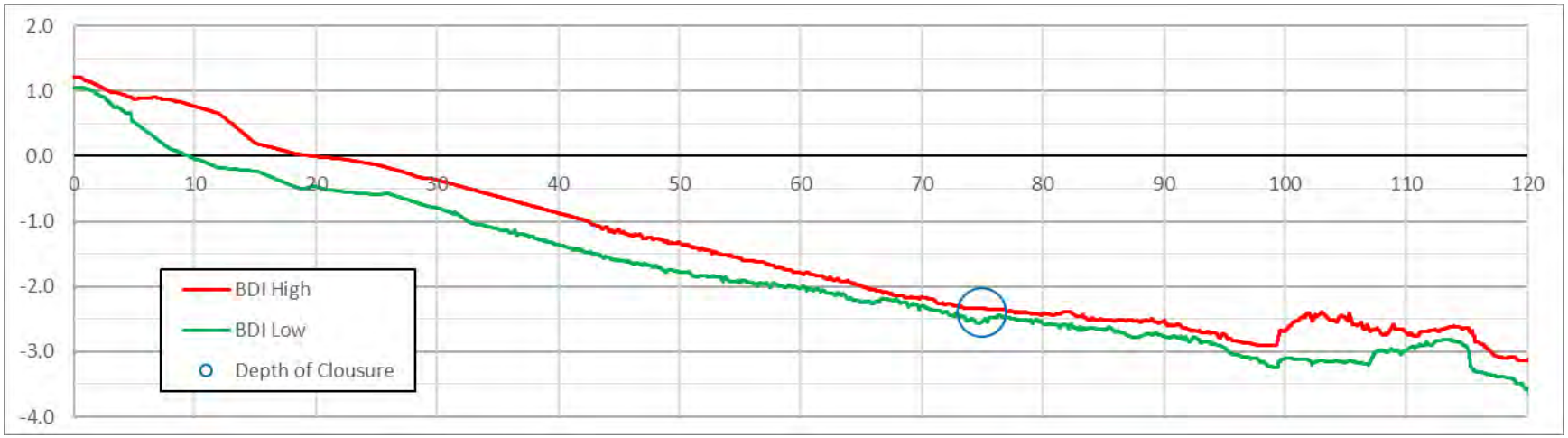

Figure J-6. Envelope of beach profiles and depth of closure at Beach 2 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

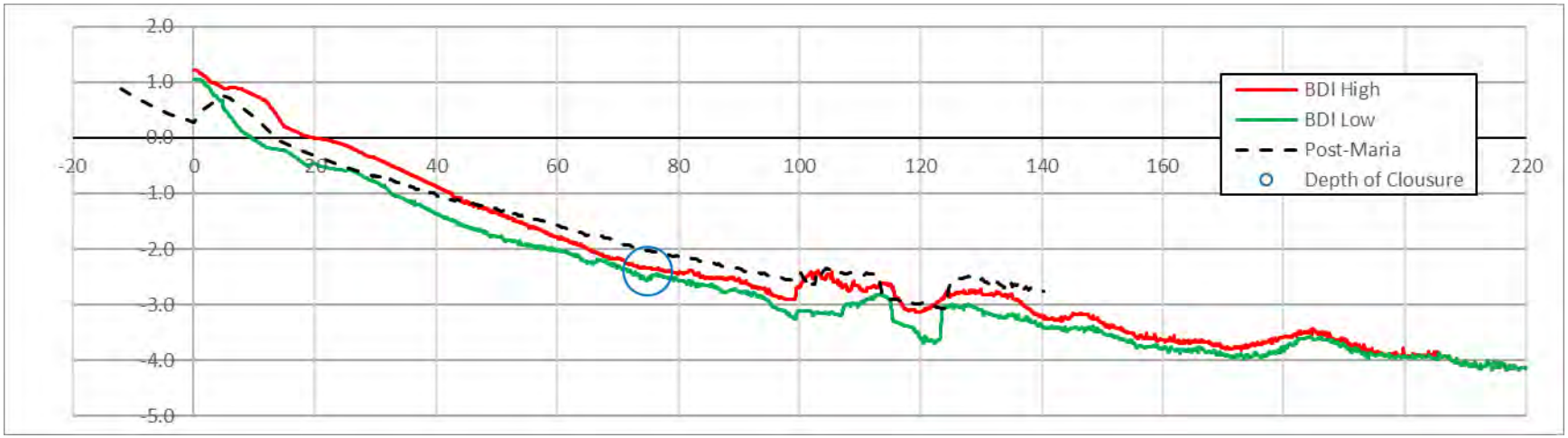

Figure J-7. Envelope of beach profiles, post-Maria profile, and depth of closure at Beach 2 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

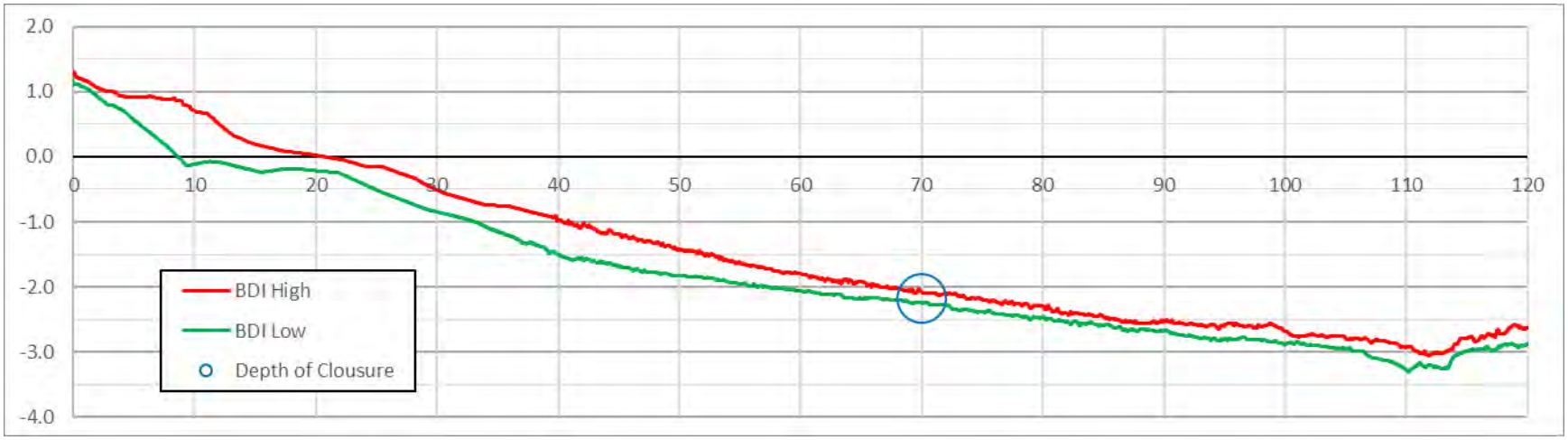

Figure J-8. Envelope of beach profiles and depth of closure at Beach 2 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

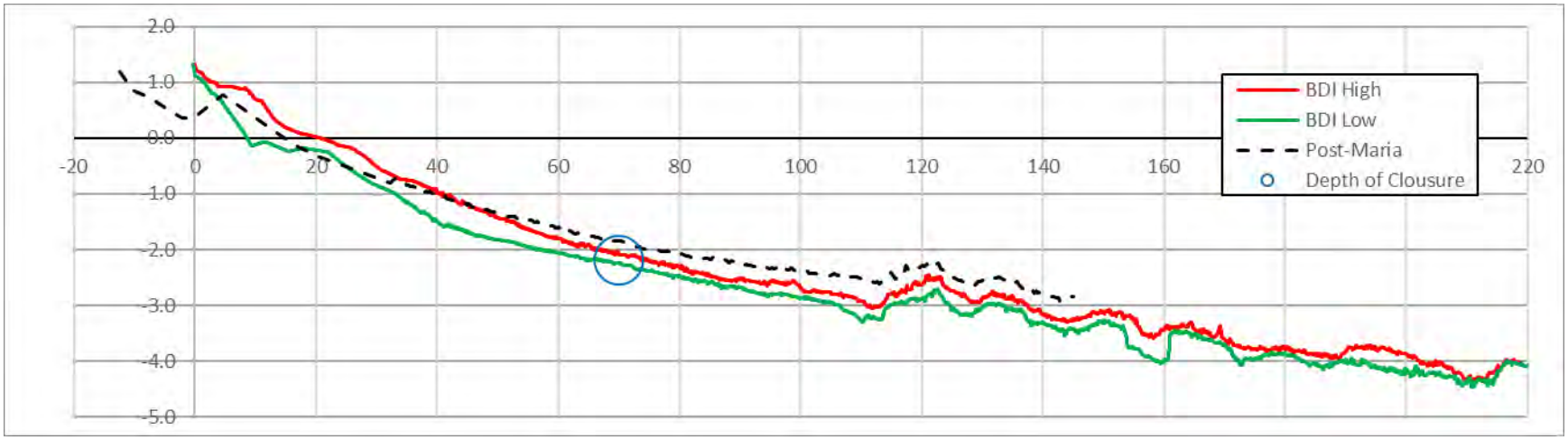

Figure J-9. Envelope of beach profiles, post-Maria profile, and depth of closure at Beach 2 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

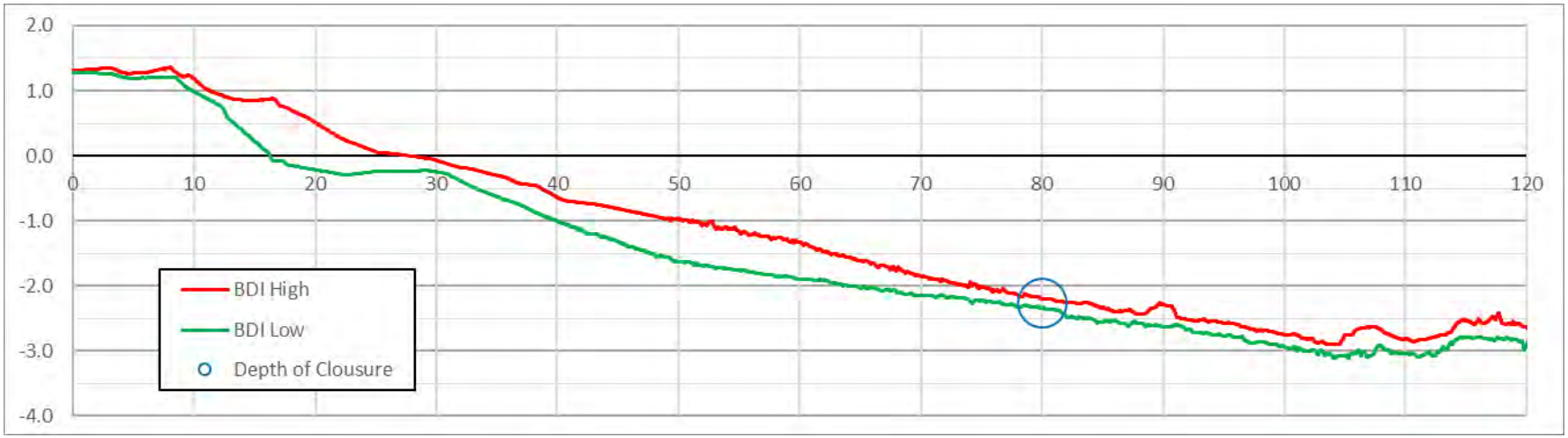

Figure J-10. Envelope of beach profiles and depth of closure at Beach 2 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

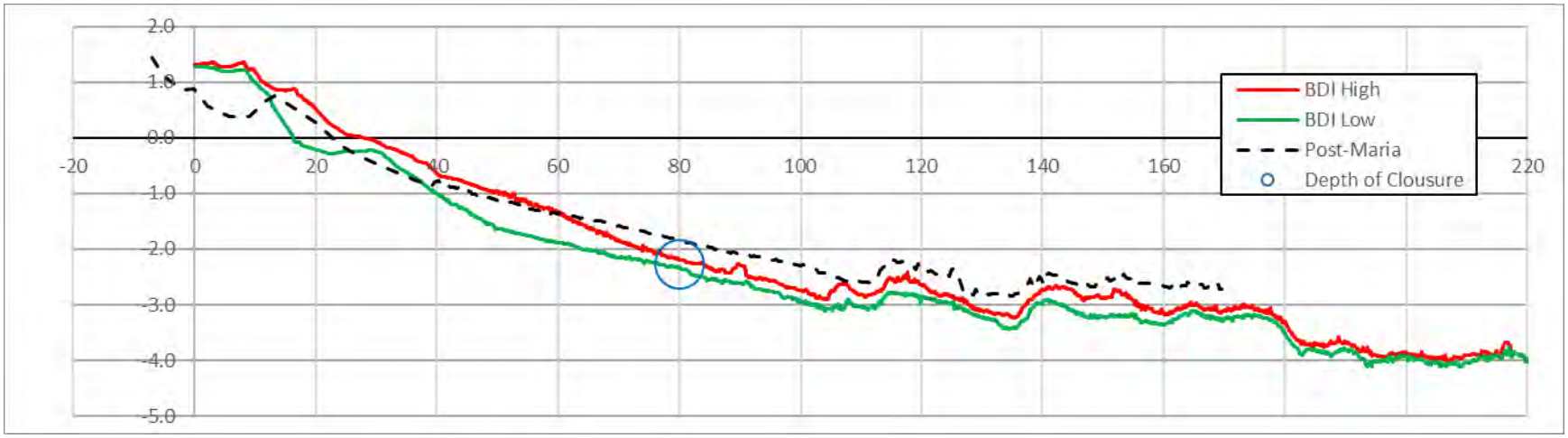

Figure J-11. Envelope of beach profiles, post-Maria profile, and depth of closure at Beach 2 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

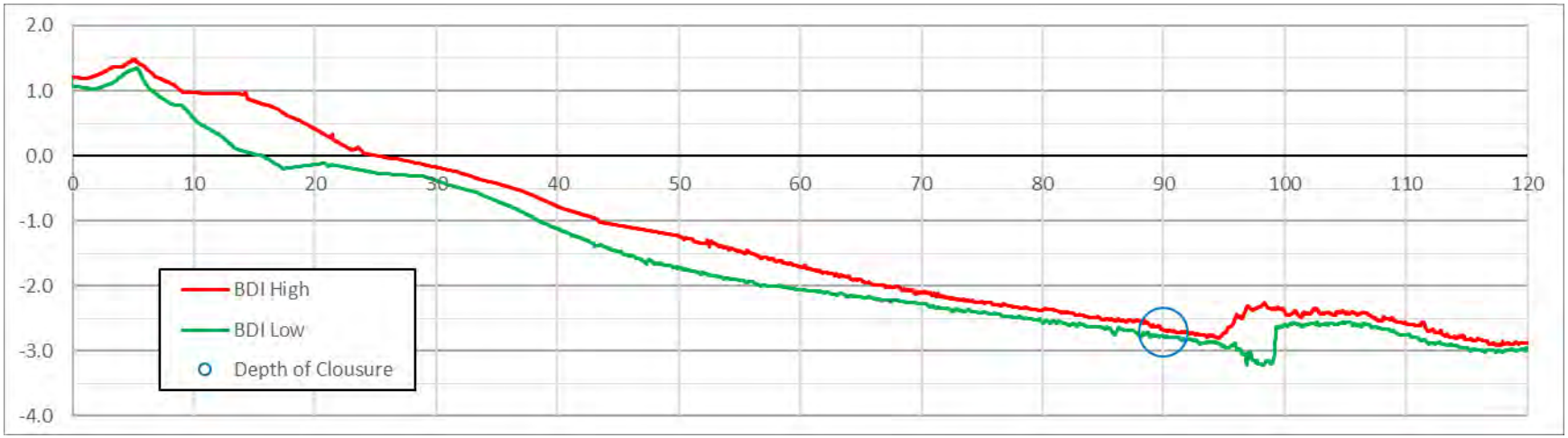

Figure J-12. Envelope of beach profiles and depth of closure at Beach 2 transect 6, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

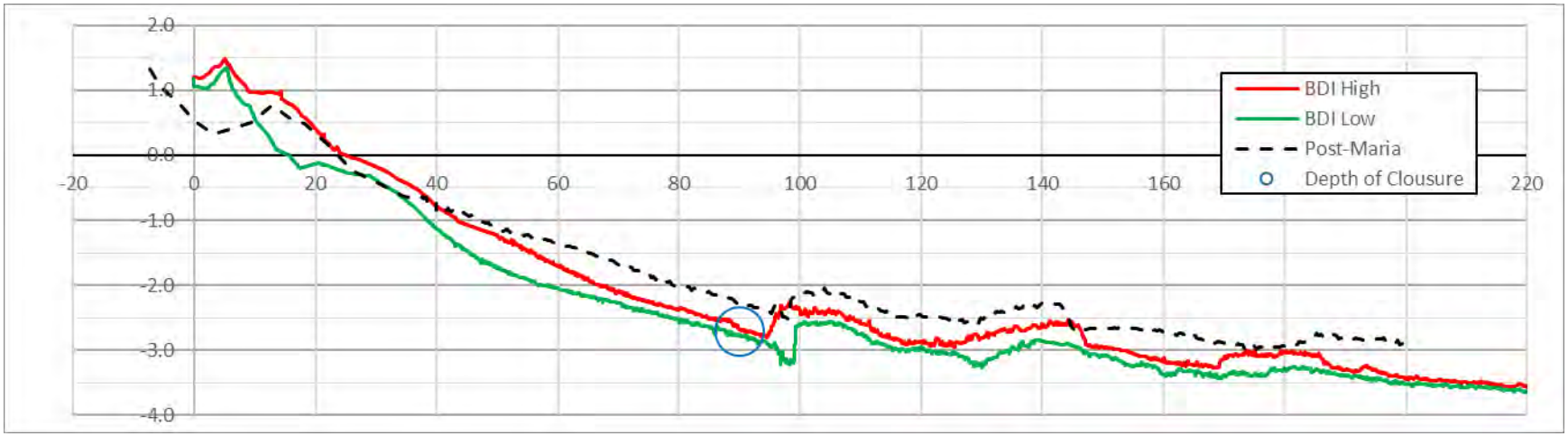

Figure J-13. Envelope of beach profiles, post-Maria profile, and depth of closure at Beach 2 transect 6, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

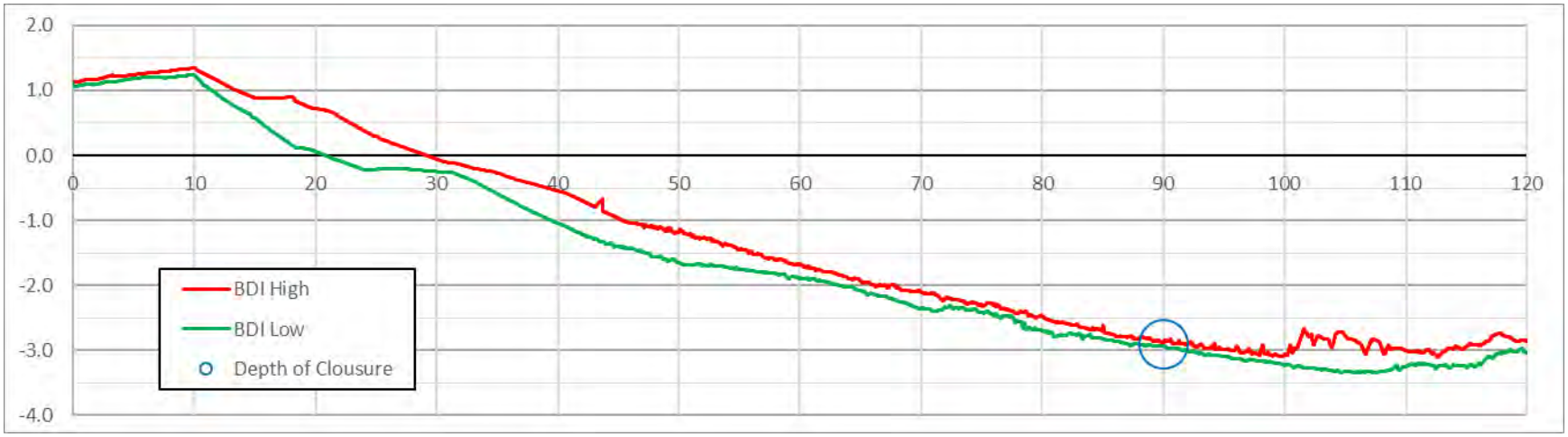

Figure J-14. Envelope of beach profiles and depth of closure at Beach 2 transect 7, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

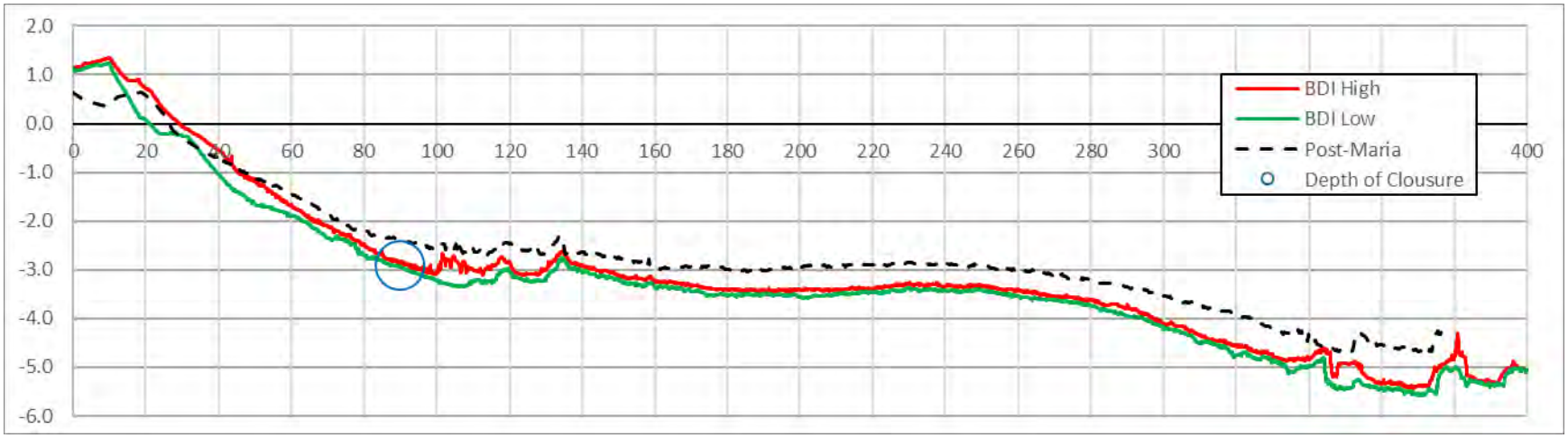

Figure J-15. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 2 transect 7, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

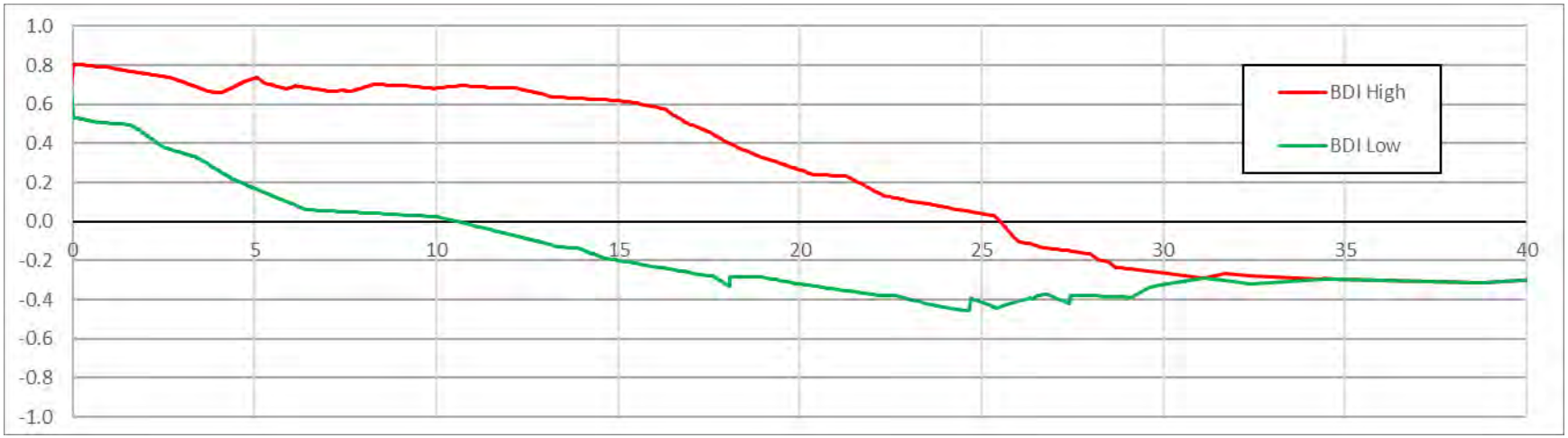

Figure J-16. Envelope of beach profiles and depth of closure at Beach 2 transect 8, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

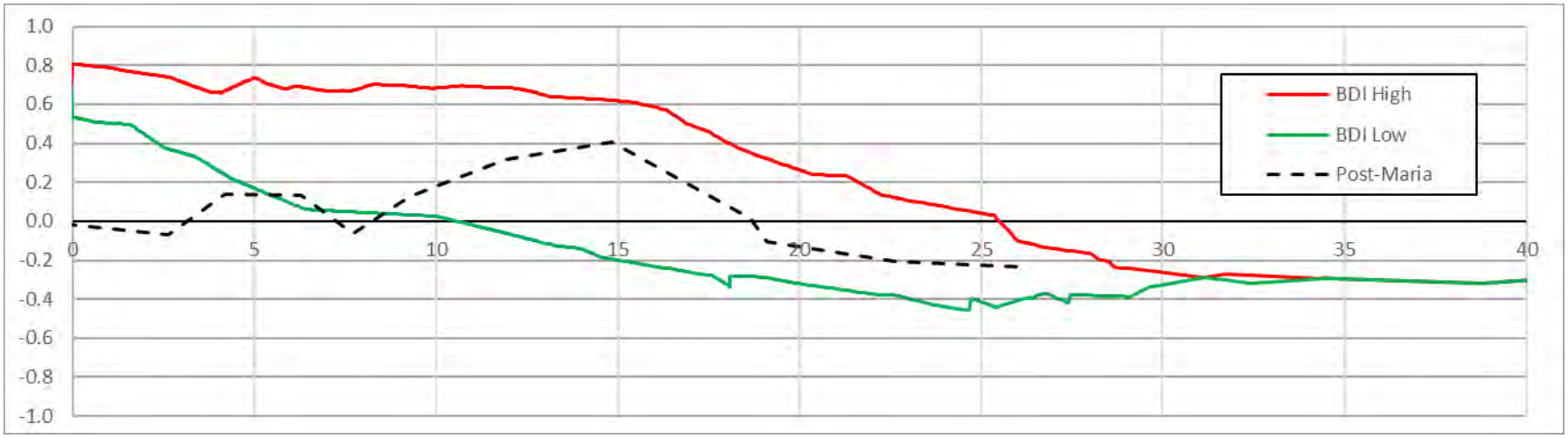

Figure J-17. Envelope of beach profiles, post-Maria profile, and depth of closure at Beach 2 transect 8, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

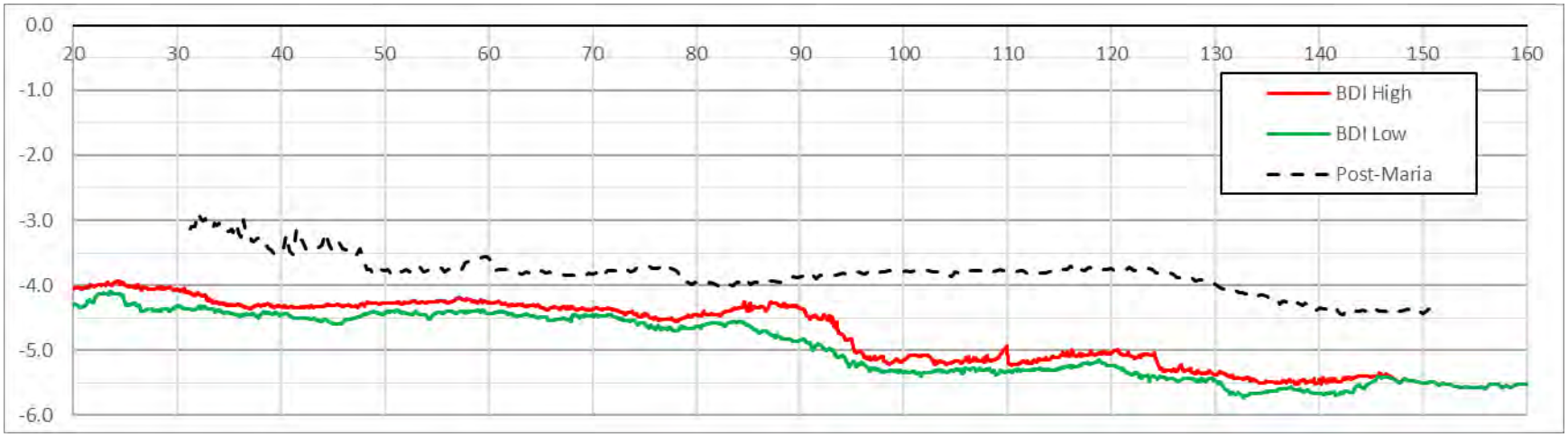

Figure J-18. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 2 transect 9, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Table J-1. Locations of depth of closure and landward limit of beach change, and width of area of beach change during the BDI and Post-Maria for Beach 2.

Transect	Depth of Closure			Landward Limit of Beach Change						Width	
				BDI			Post-Maria				
	Easting	Northing	Depth	Easting	Northing	Elevation	Easting	Northing	Elevation	BDI	Post-Maria
02-01	255,697.7	2,006,418.8	-2.54	255,622.9	2,006,450.9	0.90	255,615.9	2,006,453.9	0.80	81.4	89.0
02-02	255,722.8	2,006,467.9	-2.42	255,663.5	2,006,515.2	1.06	255,653.2	2,006,523.4	1.40	75.8	89.0
02-03	255,757.3	2,006,508.2	-2.39	255,708.8	2,006,559.1	0.86	255,695.2	2,006,573.4	1.20	70.3	90.0
02-04	255,798.2	2,006,550.9	-2.18	255,757.1	2,006,602.3	0.87	255,746.8	2,006,615.3	1.20	65.9	82.4
02-05	255,847.7	2,006,584.6	-2.26	255,811.2	2,006,642.4	0.89	255,801.2	2,006,658.3	1.43	68.4	87.1
02-06	255,905.5	2,006,609.0	-2.71	255,869.7	2,006,682.8	0.97	255,863.0	2,006,696.6	1.34	82.0	97.3
02-07	255,958.6	2,006,637.9	-2.90	255,938.0	2,006,712.9	1.08	255,933.5	2,006,729.6	1.10	77.8	95.0

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
Depth of closure and elevations of landward limit of beach change relative to PRVD02
Width (of the area of beach change) = horizontal distance along the transect between the depth of closure and landward limit of beach change

Table J-2. Locations of maximum beach elevation change, ranges, and high and low elevations of envelope for Beach 2.

Transect	Easting	Northing	Range	High	Low
02-01	255,627.8	2,006,448.7	1.02	0.86	-0.15
02-02	255,669.4	2,006,510.5	1.05	0.85	-0.20
02-03	255,713.9	2,006,553.8	0.83	0.65	-0.18
02-04	255,760.4	2,006,598.3	0.92	0.78	-0.14
02-05	255,813.9	2,006,638.3	0.96	0.88	-0.08
02-06	255,872.4	2,006,677.1	0.92	0.98	0.06
02-07	255,939.6	2,006,707.2	0.75	0.89	0.14

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
High and low elevations relative to PRVD02

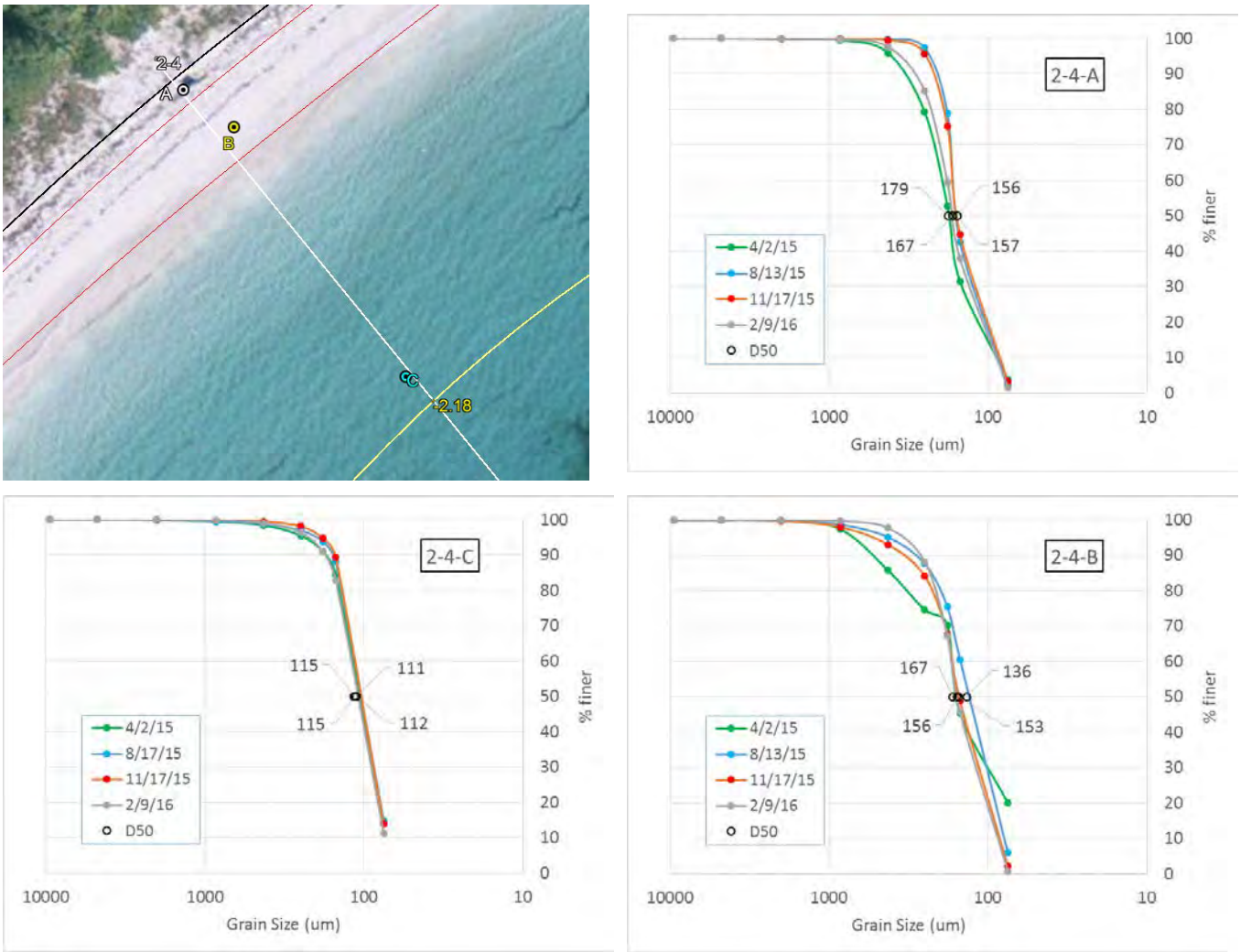

Figure J-19. Clockwise from top: approximate locations of sediment samples at Beach 2, BDI landward limit of beach change, maximum landward and seaward shoreline positions, depth of closure; and distribution of grain size at backshore (A), shoreline (B) and nearshore (C) locations.

LIA UXO 2
Beach 3

Figure J-20. Beach 3 transects, bathymetry and coastal features.

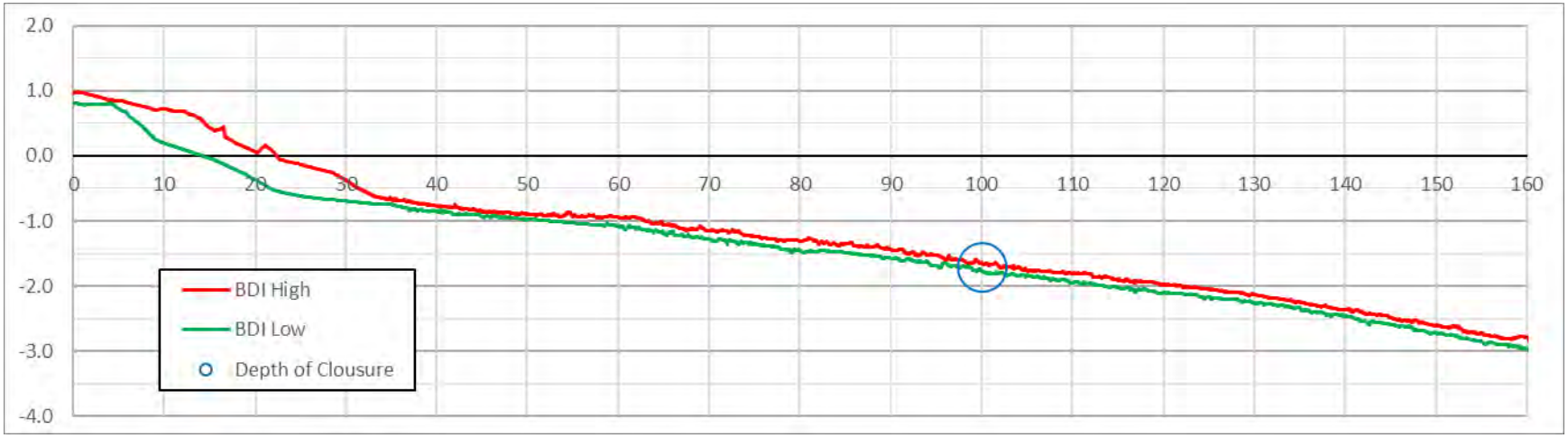

Figure J-21. Envelope of beach profiles and depth of closure at Beach 3 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

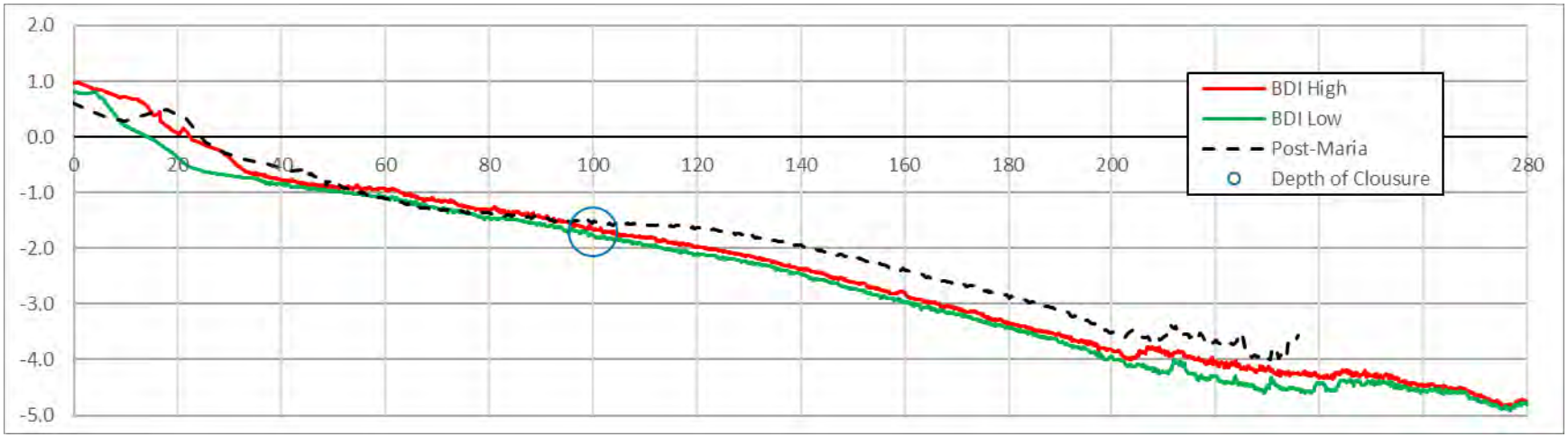

Figure J-22. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 3 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Figure Error! No text of specified style in document.-23. Envelope of beach profiles and depth of closure at Beach 3 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

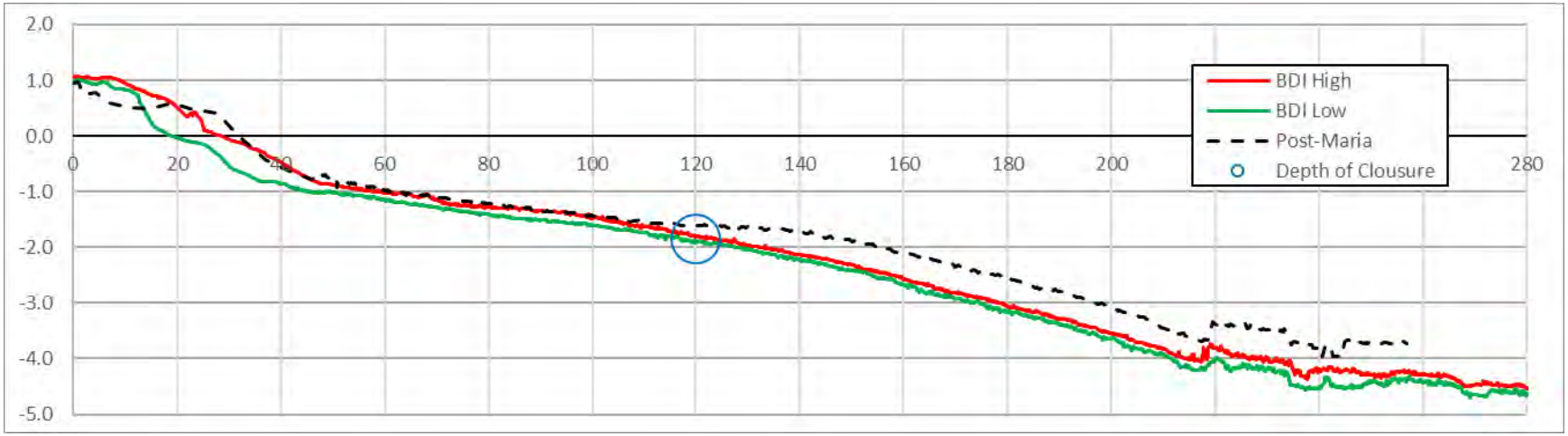

Figure J-24. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 3 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

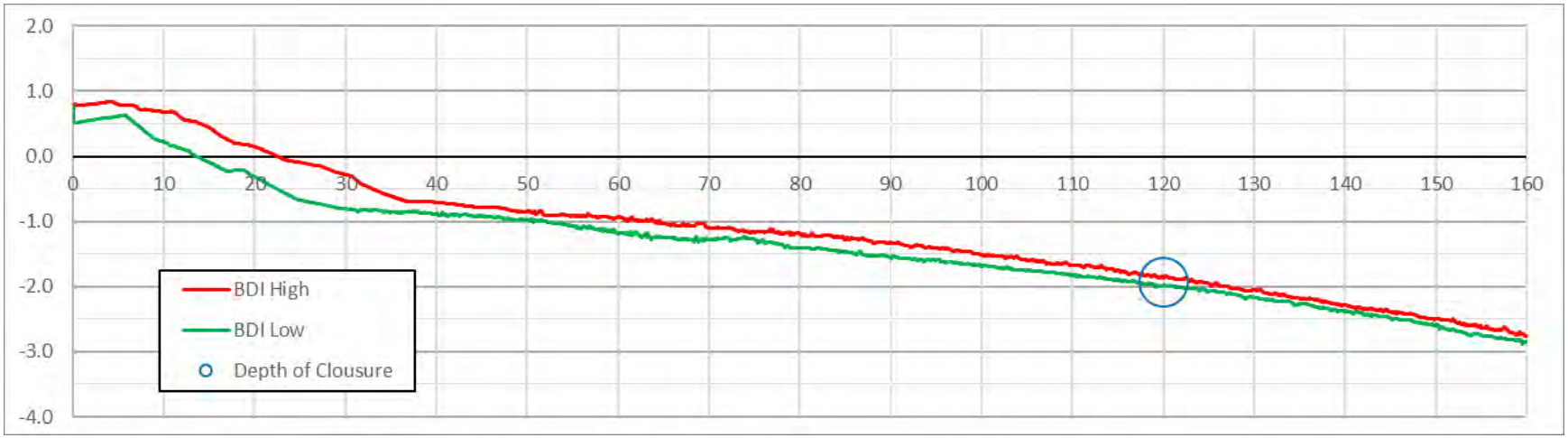

Figure J-25. Envelope of beach profiles and depth of closure at Beach 3 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

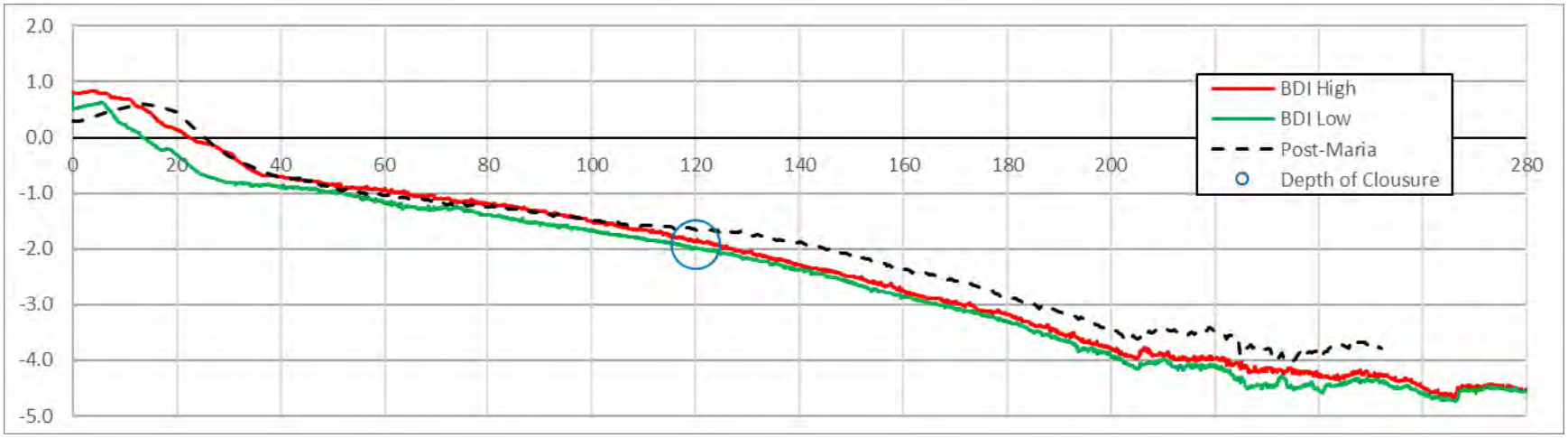

Figure J-26. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 3 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Table J-3. Locations of depth of closure and landward limit of beach change, and width of area of beach change during the BDI and Post-Maria for Beach 3.

Transect	Depth of Closure			Landward Limit of Beach Change						Width	
				BDI			Post-Maria				
	Easting	Northing	Depth	Easting	Northing	Elevation	Easting	Northing	Elevation	BDI	Post-Maria
03-01	256,166.6	2,006,651.9	-1.71	256,113.7	2,006,731.1	0.81	256,108.3	2,006,739.2	1.00	95.3	105.0
03-02	256,184.8	2,006,651.8	-1.85	256,135.3	2,006,748.5	0.85	256,130.6	2,006,757.7	1.00	108.6	119.0
03-03	256,204.3	2,006,650.6	-1.93	256,166.3	2,006,759.7	0.80	256,163.2	2,006,768.6	1.00	115.6	125.0

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
Depth of closure and elevations of landward limit of beach change relative to PRVD02
Width (of the area of beach change) = horizontal distance along the transect between the depth of closure and landward limit of beach change

Table J-4. Locations of maximum beach elevation change, ranges, and high and low elevations of envelope for Beach 3.

Transect	Easting	Northing	Range	High	Low
03-01	256,122.9	2,006,717.4	0.62	0.16	-0.46
03-02	256,138.6	2,006,742.0	0.62	0.63	0.01
03-03	256,173.8	2,006,738.1	0.59	-0.15	-0.74

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
High and low elevations relative to PRVD02

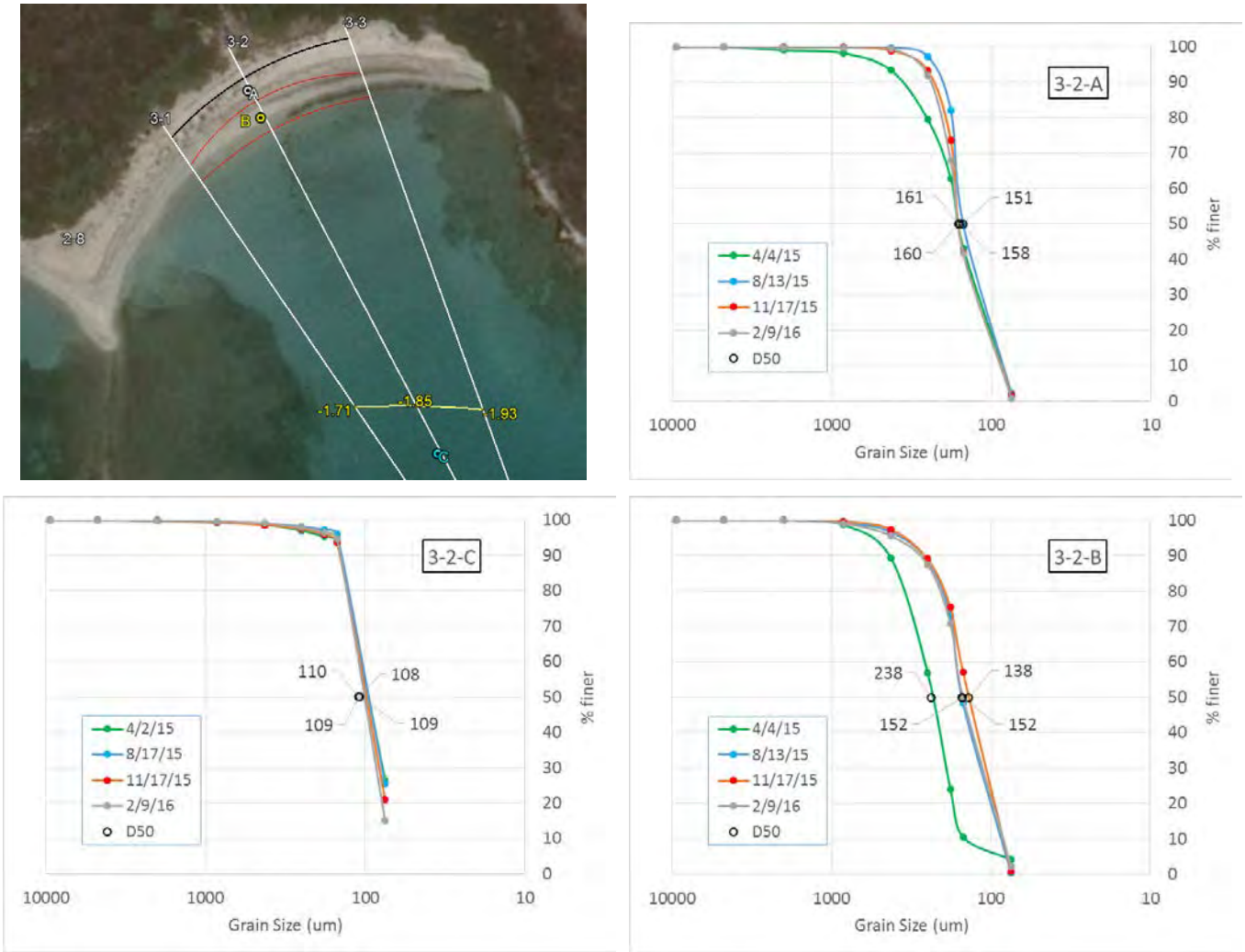

Figure J-27. Clockwise from top: approximate locations of sediment samples at Beach 3, BDI landward limit of beach change, maximum landward and seaward shoreline positions, depth of closure; and distribution of grain size at backshore (A), shoreline (B) and nearshore (C) locations.

LIA UXO 2
Beach 4

Figure J-28. Beach 4 transects, bathymetry and coastal features.

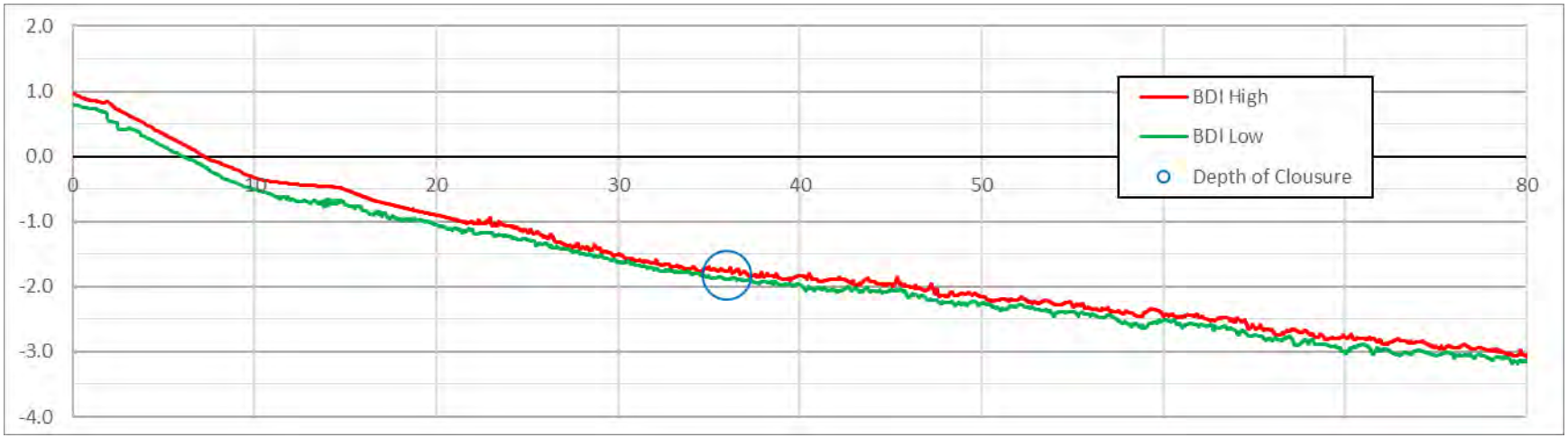

Figure J-29. Envelope of beach profiles and depth of closure at Beach 4 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

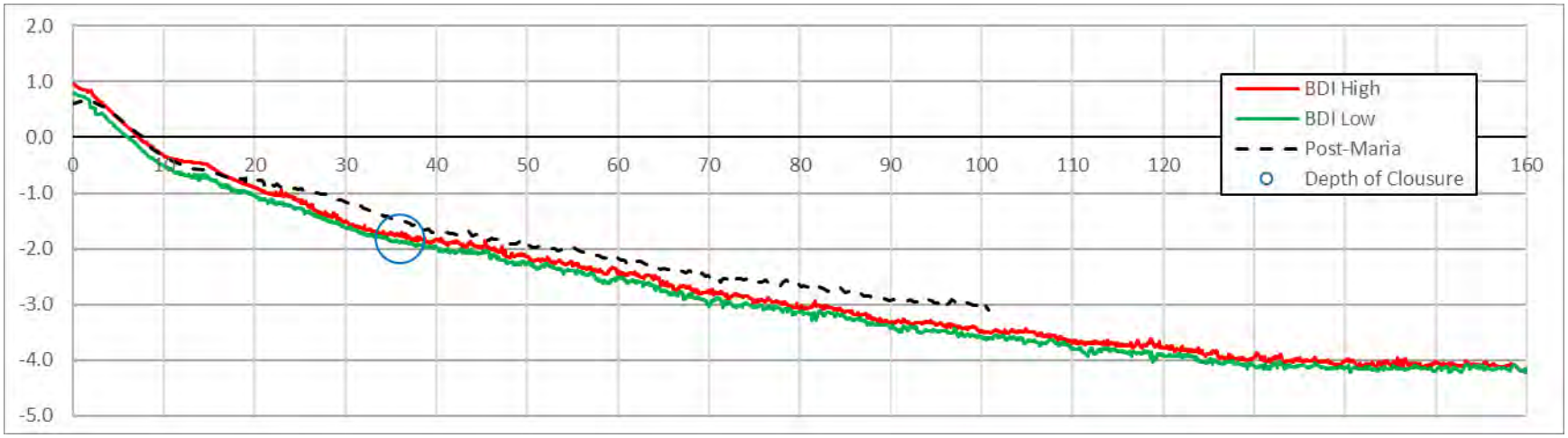

Figure J-30. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 4 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

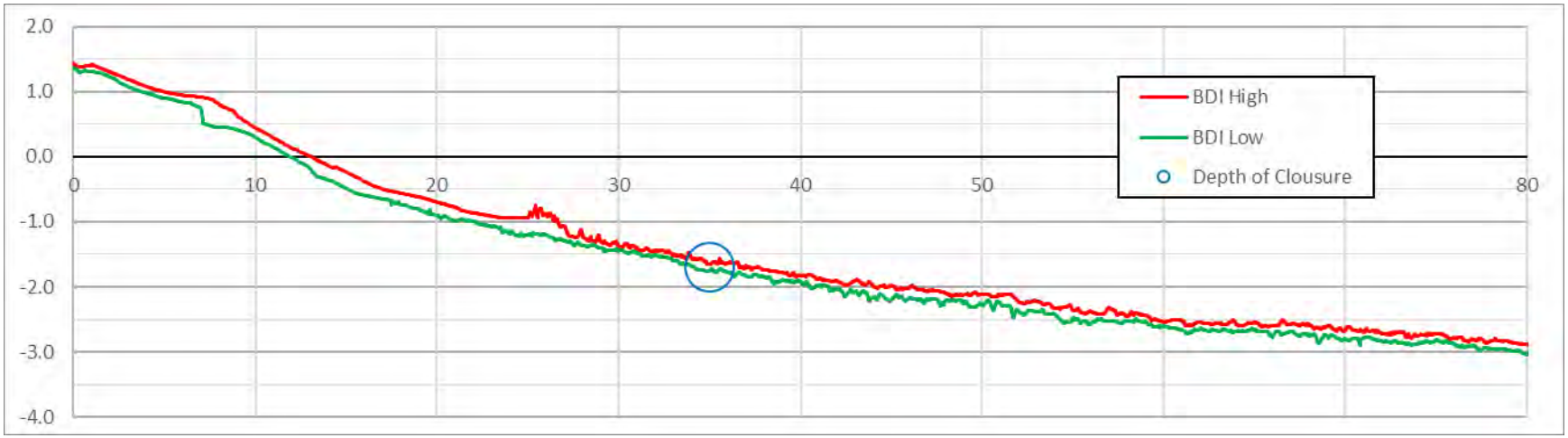

Figure J-31. Envelope of beach profiles and depth of closure at Beach 4 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

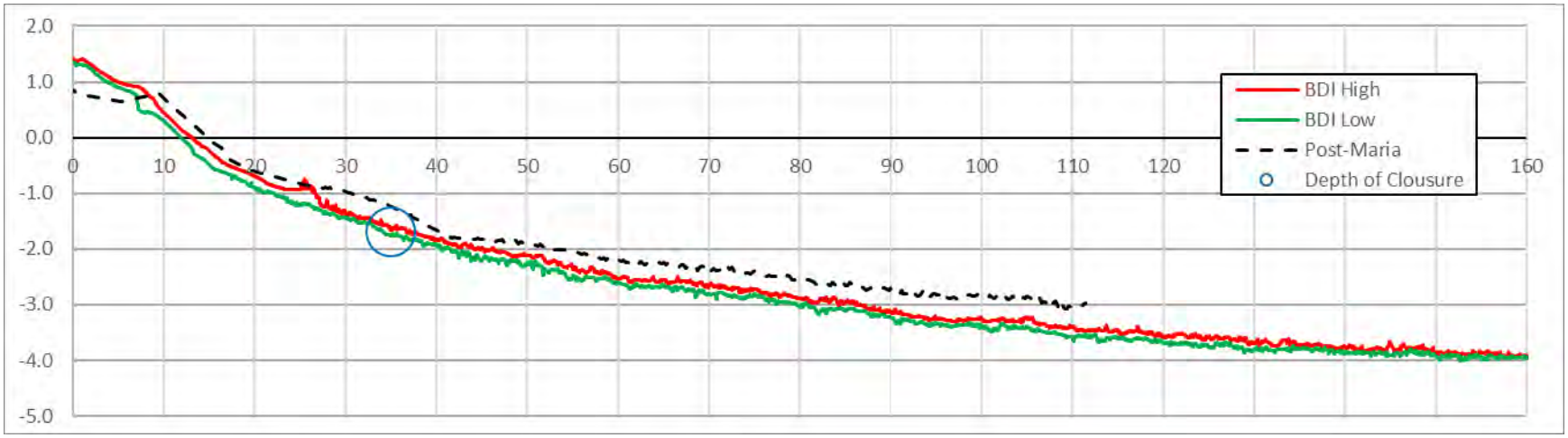

Figure J-32. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 4 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

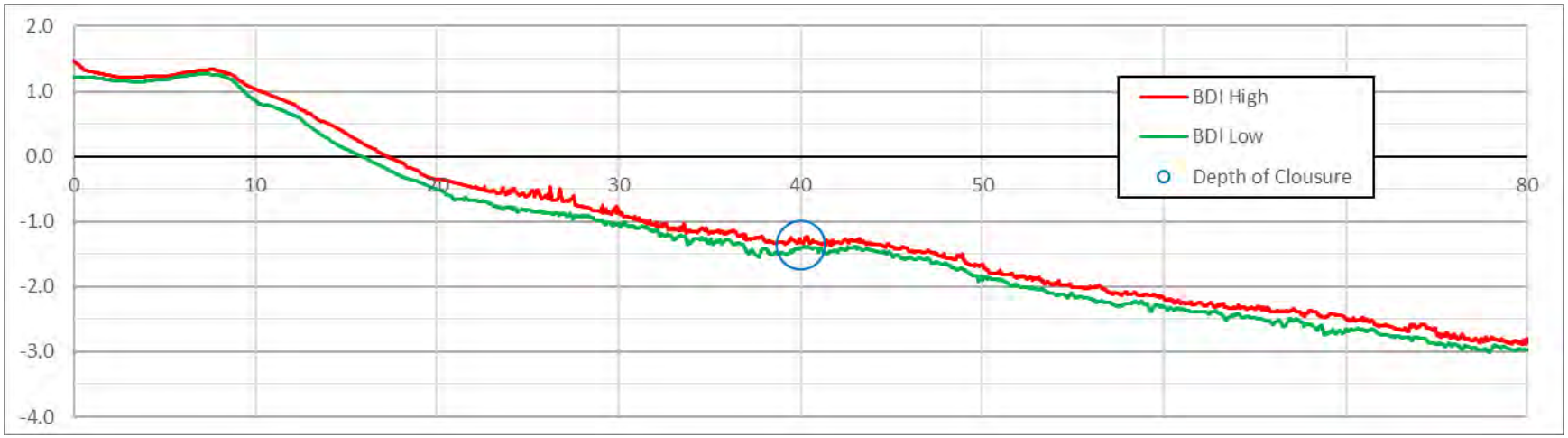

Figure J-33. Envelope of beach profiles and depth of closure at Beach 4 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

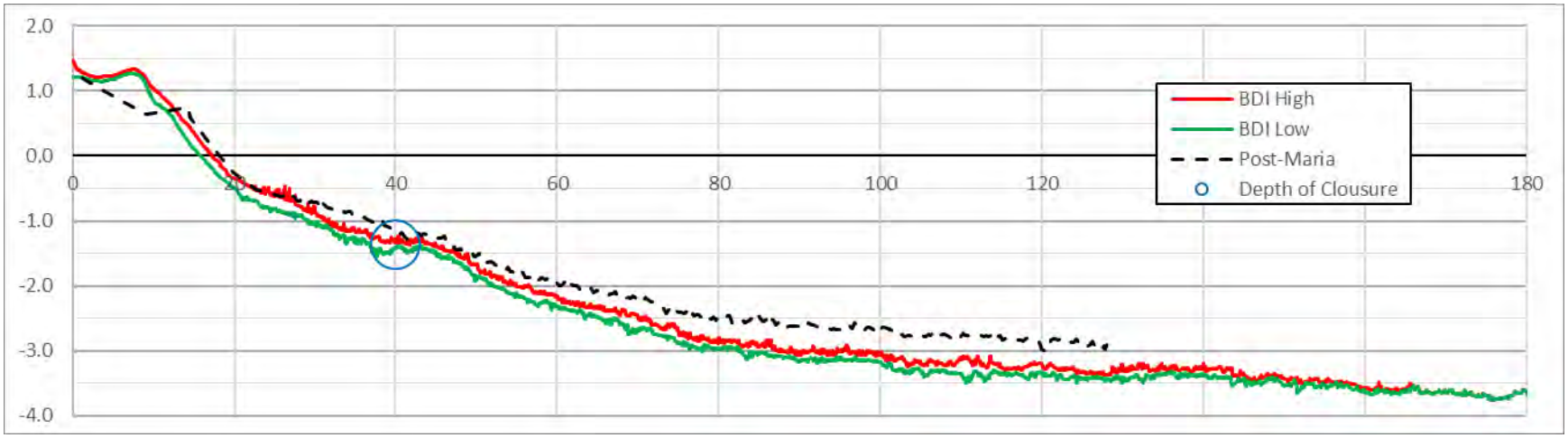

Figure J-34. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 4 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

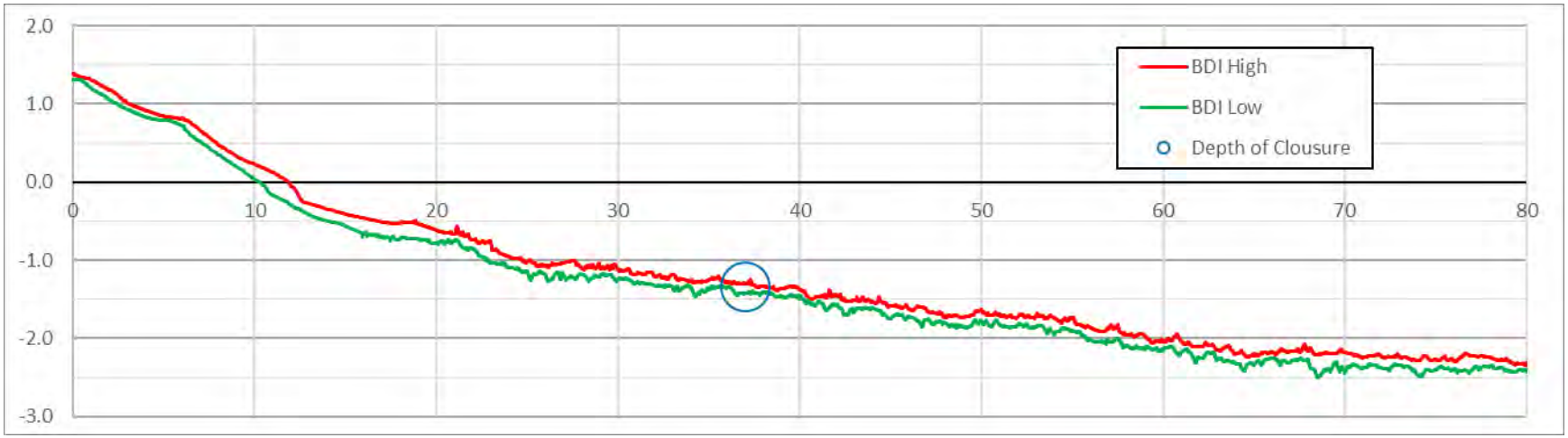

Figure J-35. Envelope of beach profiles and depth of closure at Beach 4 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

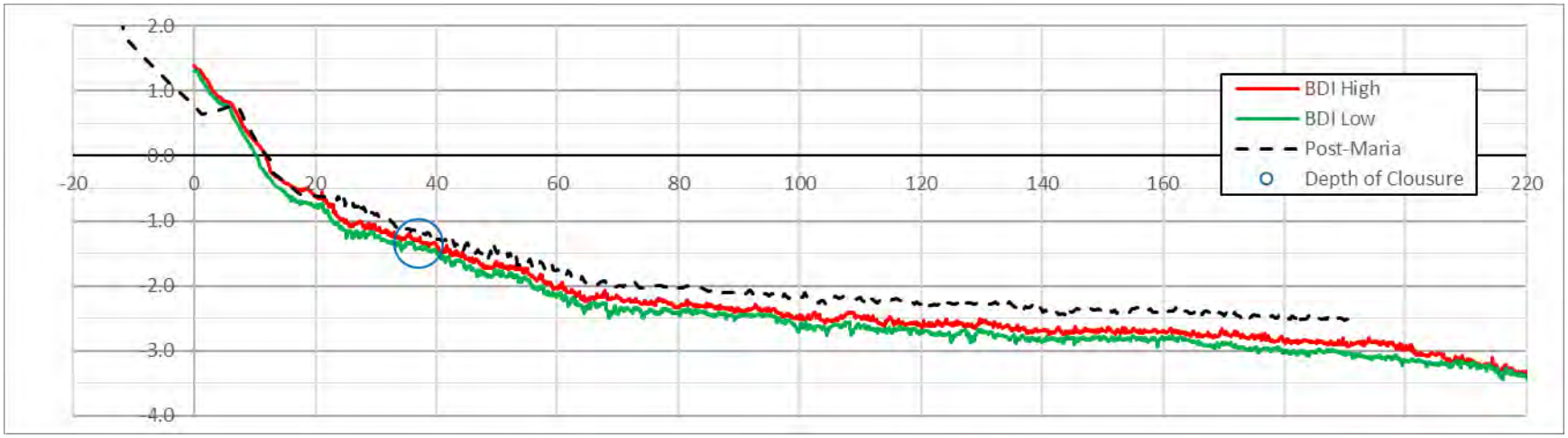

Figure J-36. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 4 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

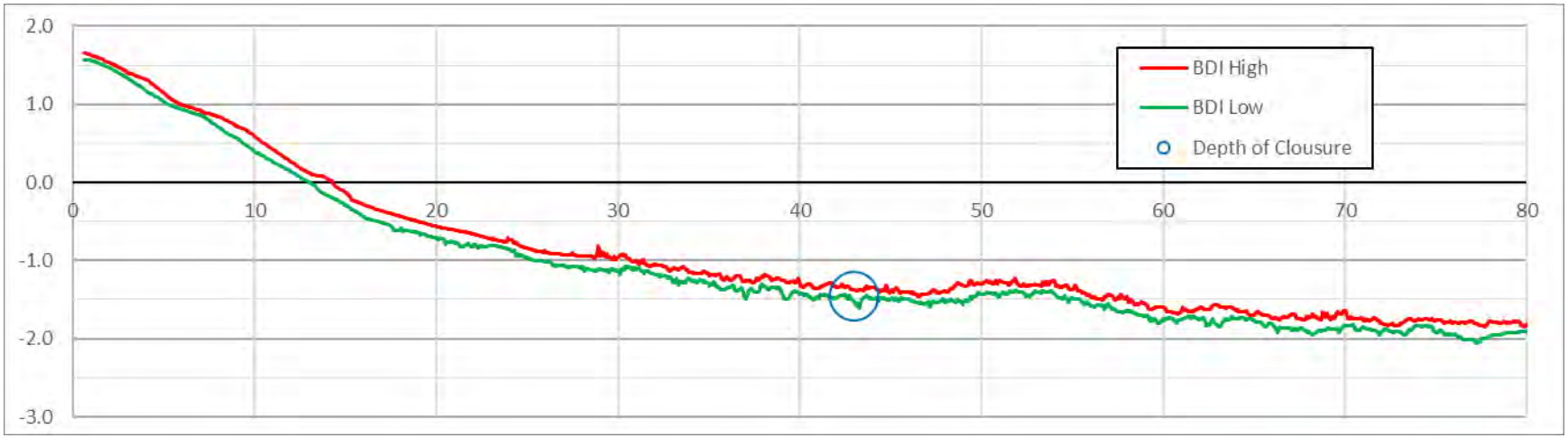

Figure J-37. Envelope of beach profiles and depth of closure at Beach 4 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

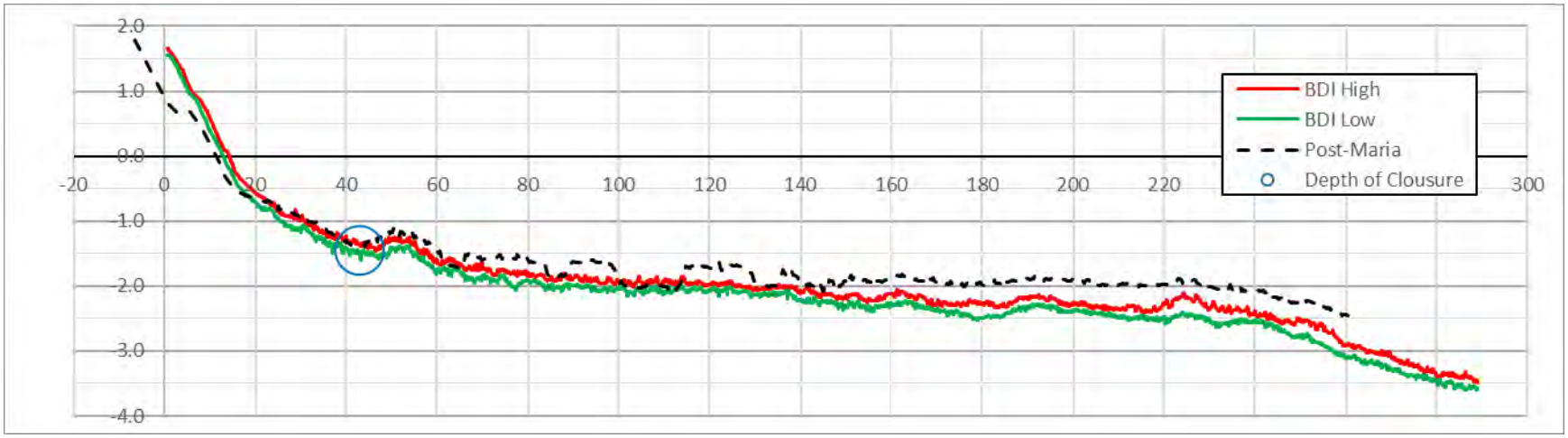

Figure J-38. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 4 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

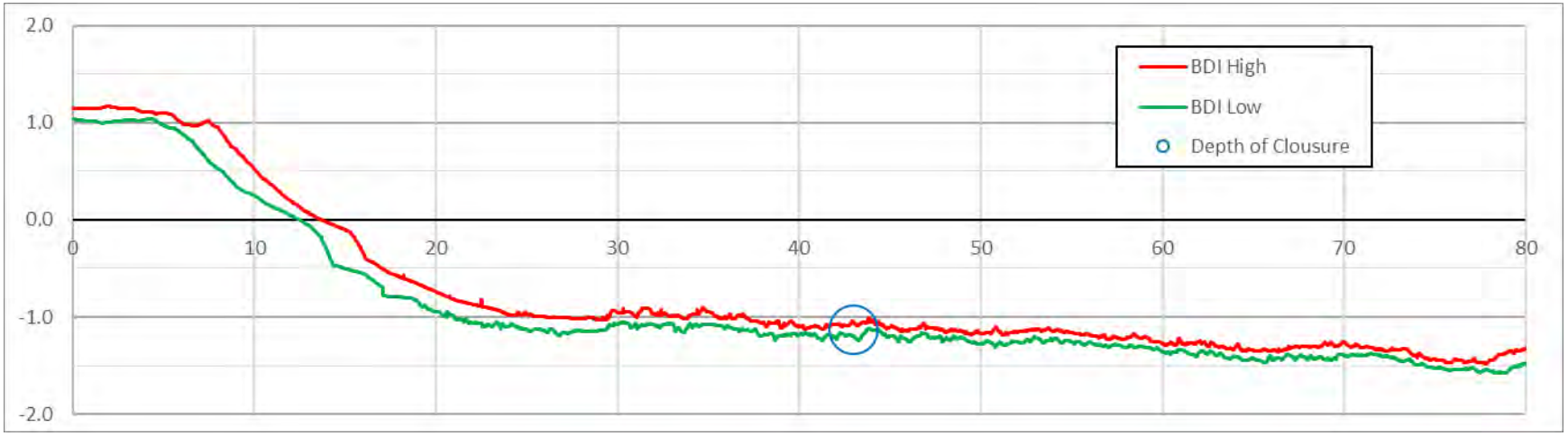

Figure J-39. Envelope of beach profiles and depth of closure at Beach 4 transect 6, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

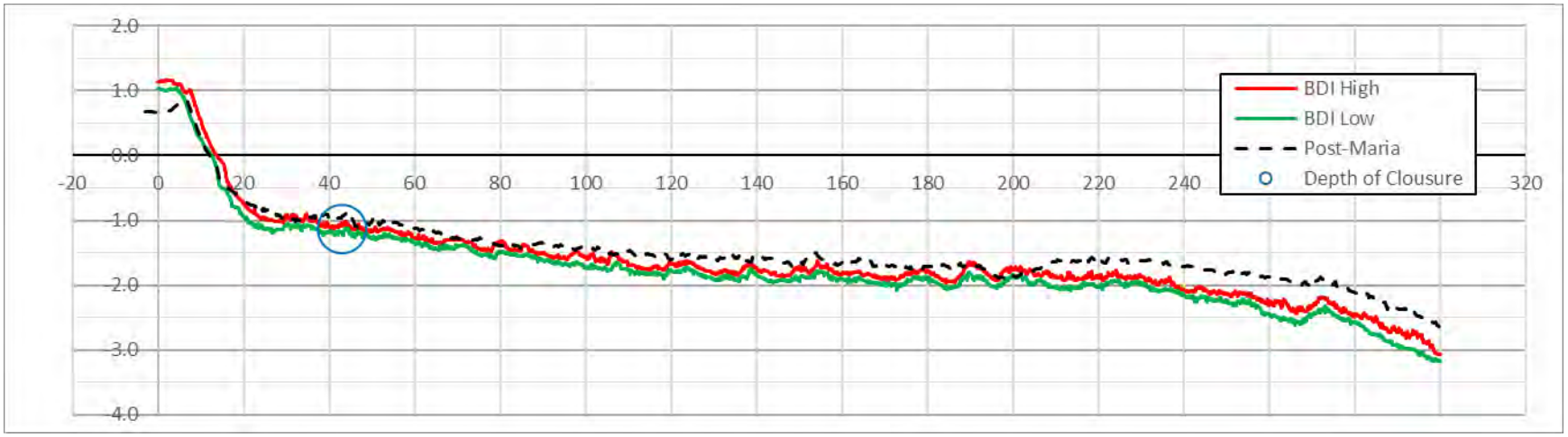

Figure J-40. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 4 transect 6, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Table J-5. Locations of depth of closure and landward limit of beach change, and width of area of beach change during the BDI and Post-Maria for Beach 4.

Transect	Depth of Closure			Landward Limit of Beach Change						Width	
				BDI			Post-Maria				
	Easting	Northing	Depth	Easting	Northing	Elevation	Easting	Northing	Elevation	BDI	Post-Maria
04-01	256,546.6	2,006,683.0	-1.83	256,543.9	2,006,717.1	0.82	256,543.8	2,006,718.9	0.62	34.2	36.0
04-02	256,611.9	2,006,681.0	-1.70	256,619.9	2,006,707.8	0.87	256,623.7	2,006,720.3	1.40	28.0	41.0
04-03	256,668.3	2,006,655.2	-1.36	256,684.6	2,006,681.0	1.04	256,690.8	2,006,690.9	1.50	30.5	42.2
04-04	256,716.4	2,006,621.1	-1.34	256,737.2	2,006,645.1	0.80	256,744.6	2,006,653.8	1.31	31.8	43.2
04-05	256,757.3	2,006,579.8	-1.45	256,783.5	2,006,604.1	0.84	256,792.3	2,006,612.3	1.56	35.8	47.8
04-06	256,801.4	2,006,524.0	-1.13	256,833.0	2,006,545.4	1.04	256,839.5	2,006,549.8	0.68	38.2	46.0

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
Depth of closure and elevations of landward limit of beach change relative to PRVD02
Width (of the area of beach change) = horizontal distance along the transect between the depth of closure and landward limit of beach change

Table J-6. Locations of maximum beach elevation change, ranges, and high and low elevations of envelope for Beach 4.

Transect	Easting	Northing	Range	High	Low
04-01	256,544.9	2,006,705.1	0.30	-0.46	-0.76
04-02	256,619.8	2,006,707.3	0.42	0.88	0.46
04-03	256,681.8	2,006,676.7	0.25	0.41	0.16
04-04	256,733.4	2,006,640.7	0.30	0.12	-0.18
04-05	256,778.6	2,006,599.6	0.22	0.07	-0.16
04-06	256,830.3	2,006,543.6	0.42	0.95	0.53

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
High and low elevations relative to PRVD02

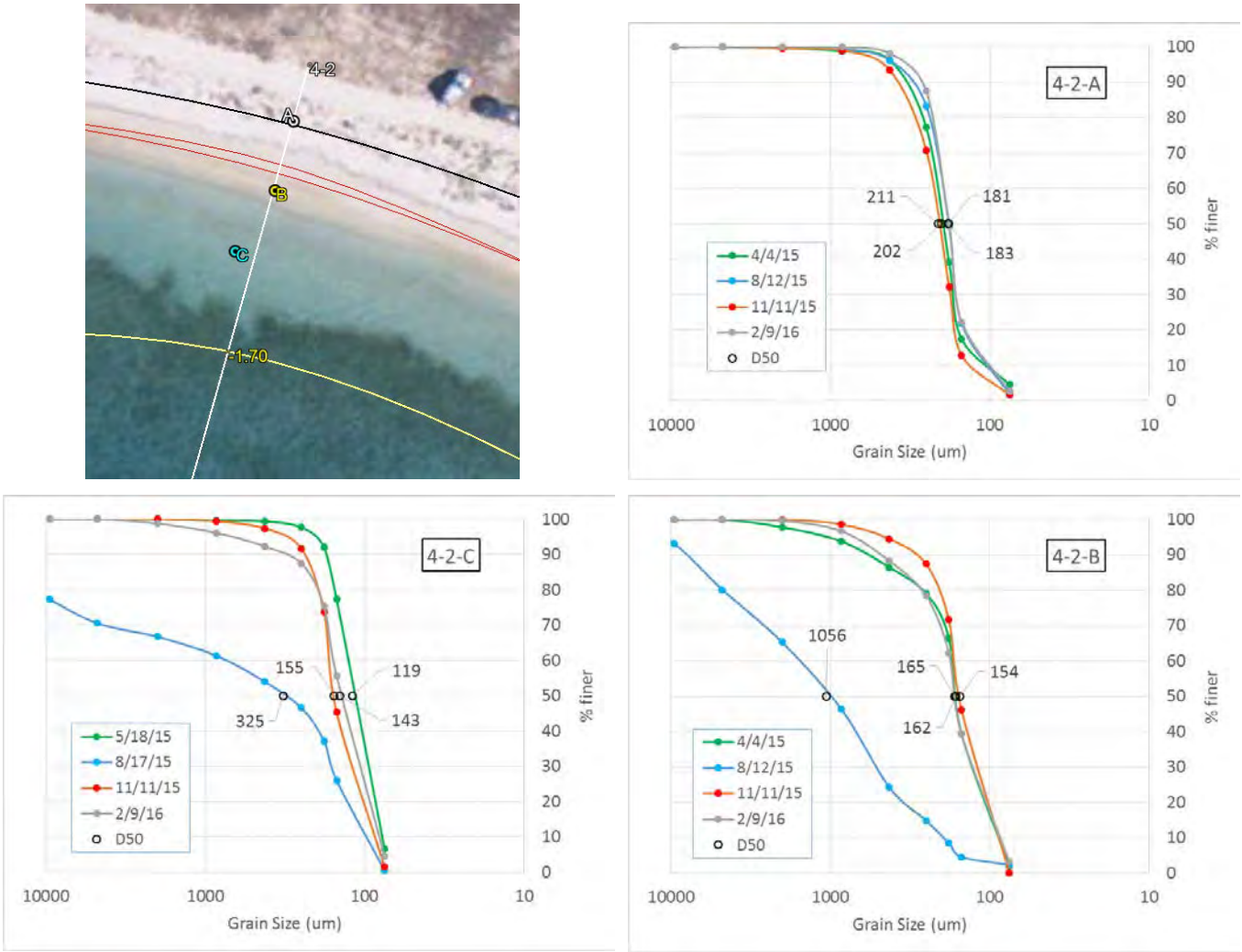

Figure J-41. Clockwise from top: approximate locations of sediment samples at Beach 4, BDI landward limit of beach change, maximum landward and seaward shoreline positions, depth of closure; and distribution of grain size at backshore (A), shoreline (B) and nearshore (C) locations.

LIA UXO 2
Beach 5

Figure J-42. Beach 5 transects, bathymetry and coastal features.

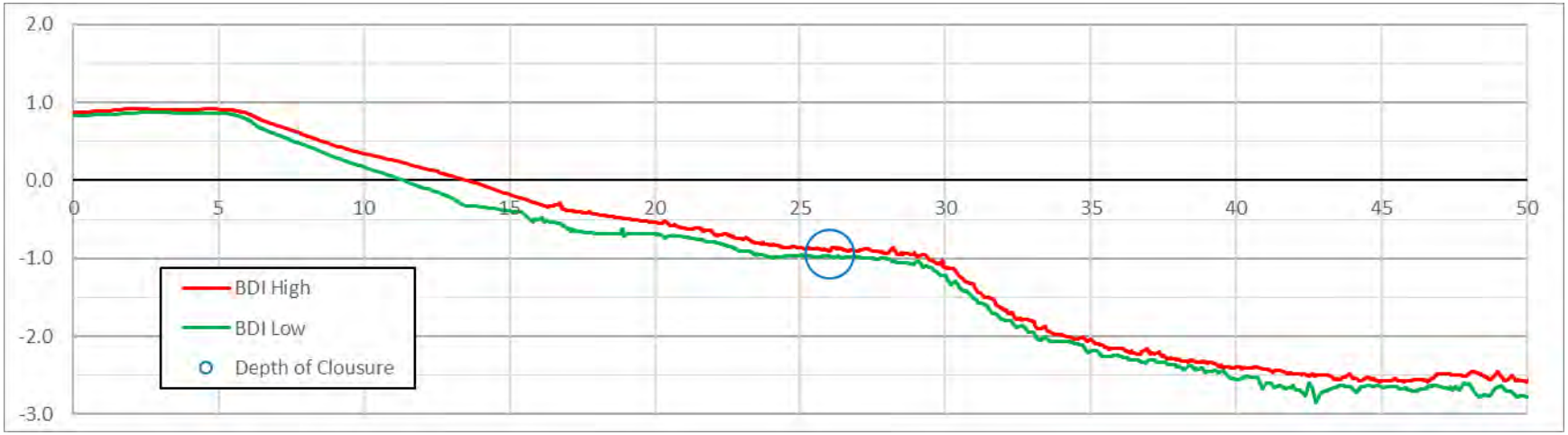

Figure J-43. Envelope of beach profiles and depth of closure at Beach 5 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

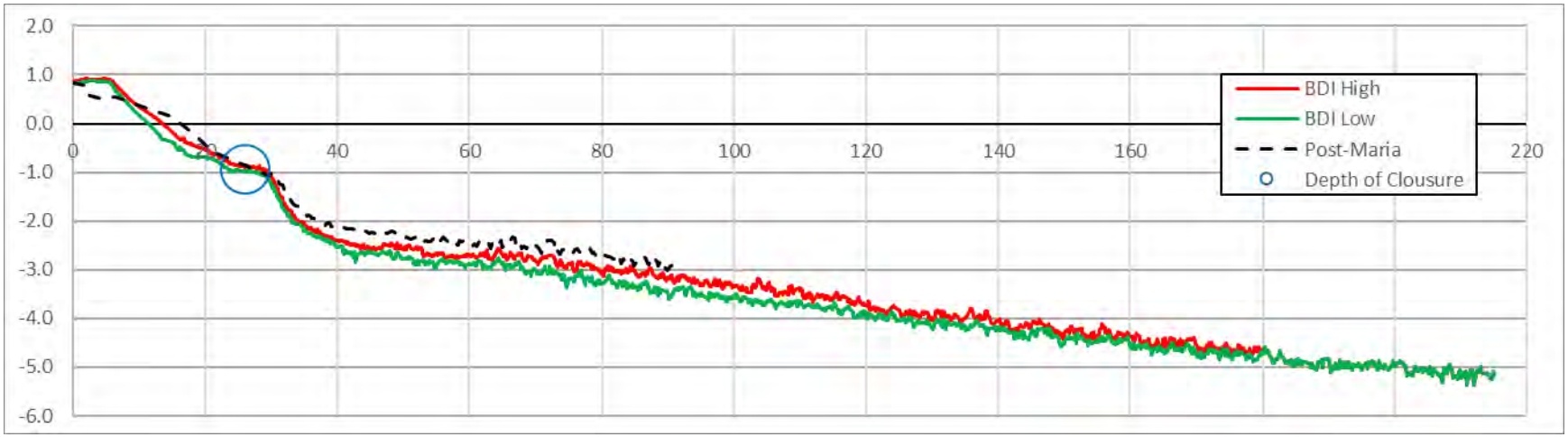

Figure J-44. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 5 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

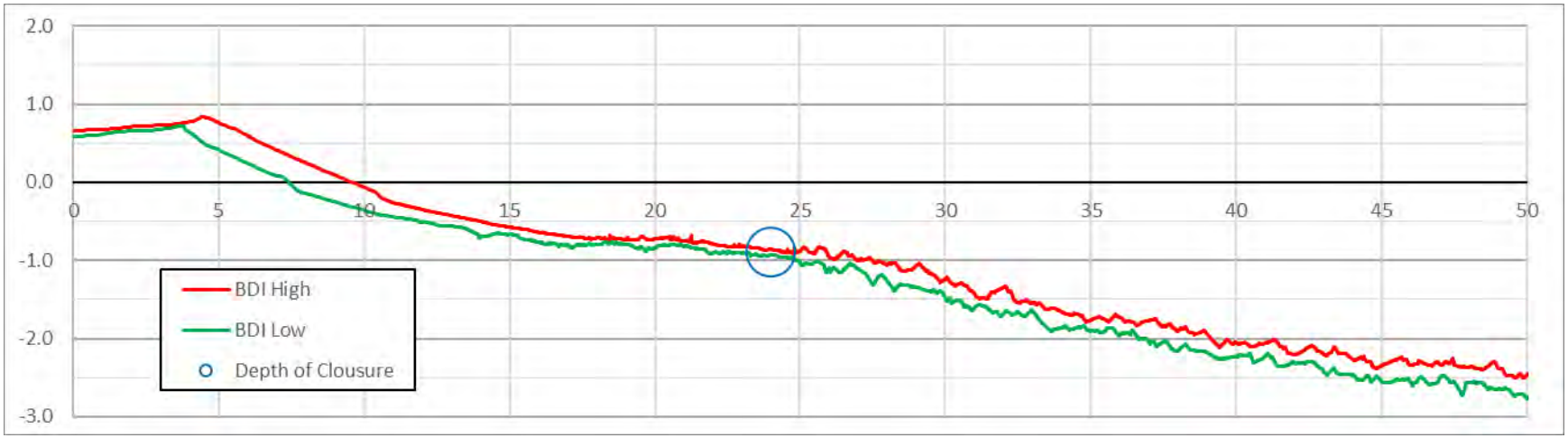

Figure J-45. Envelope of beach profiles and depth of closure at Beach 5 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

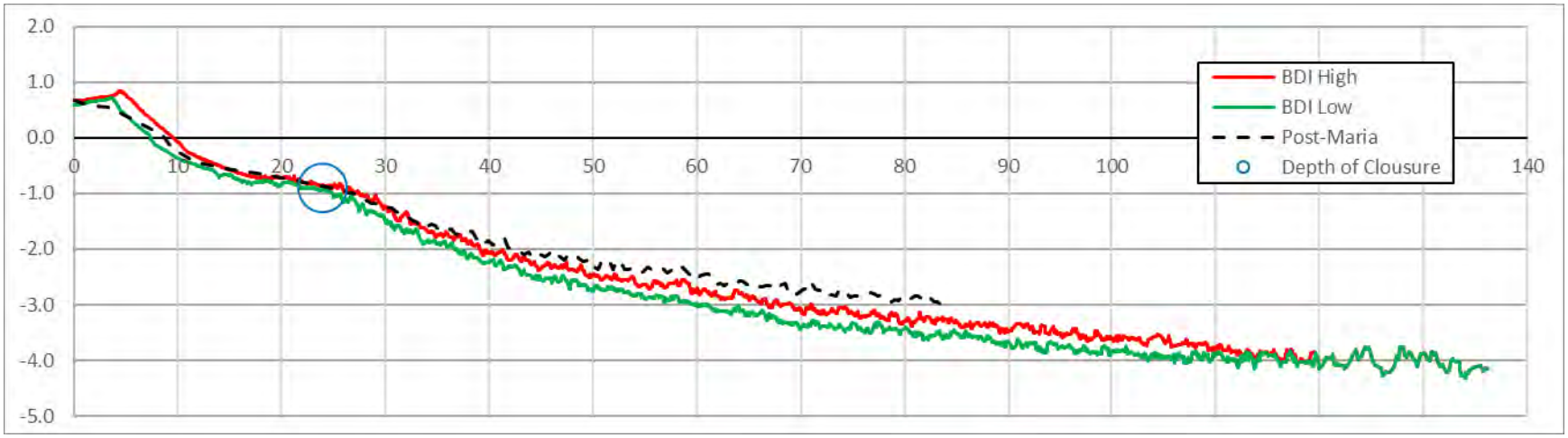

Figure J-46. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 5 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

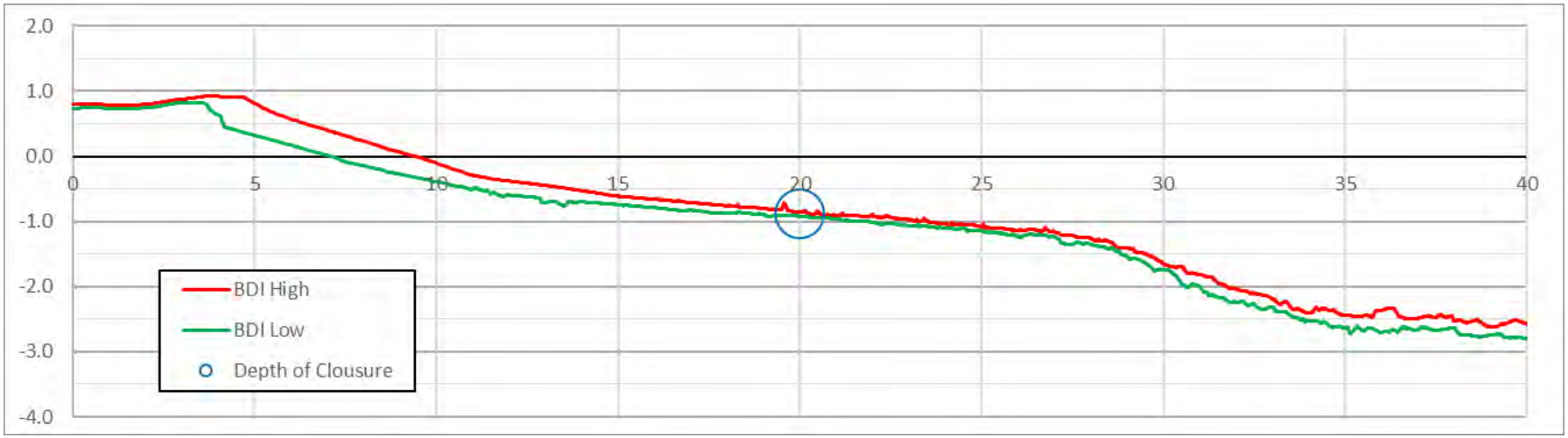

Figure J-47. Envelope of beach profiles and depth of closure at Beach 5 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

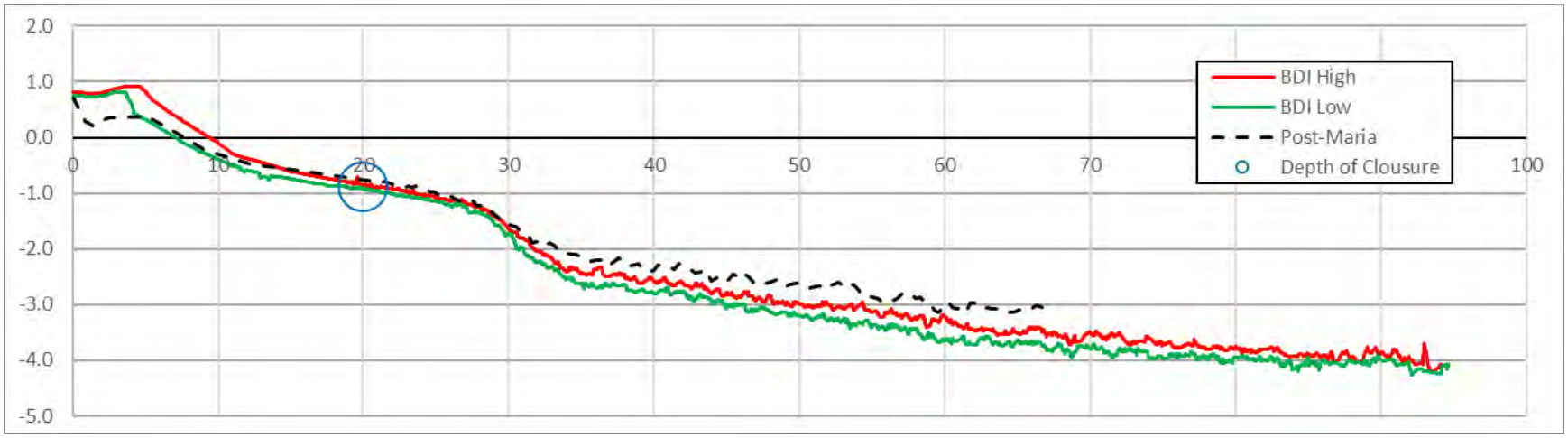

Figure J-48. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 5 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Figure J-49. Envelope of beach profiles and depth of closure at Beach 5 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

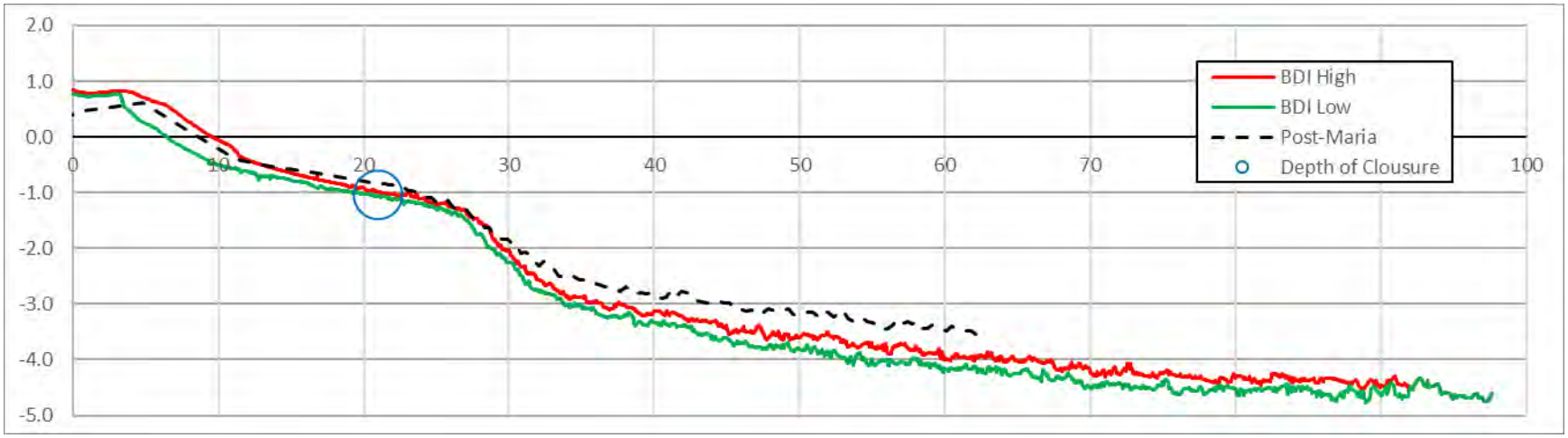

Figure J-50. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 5 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

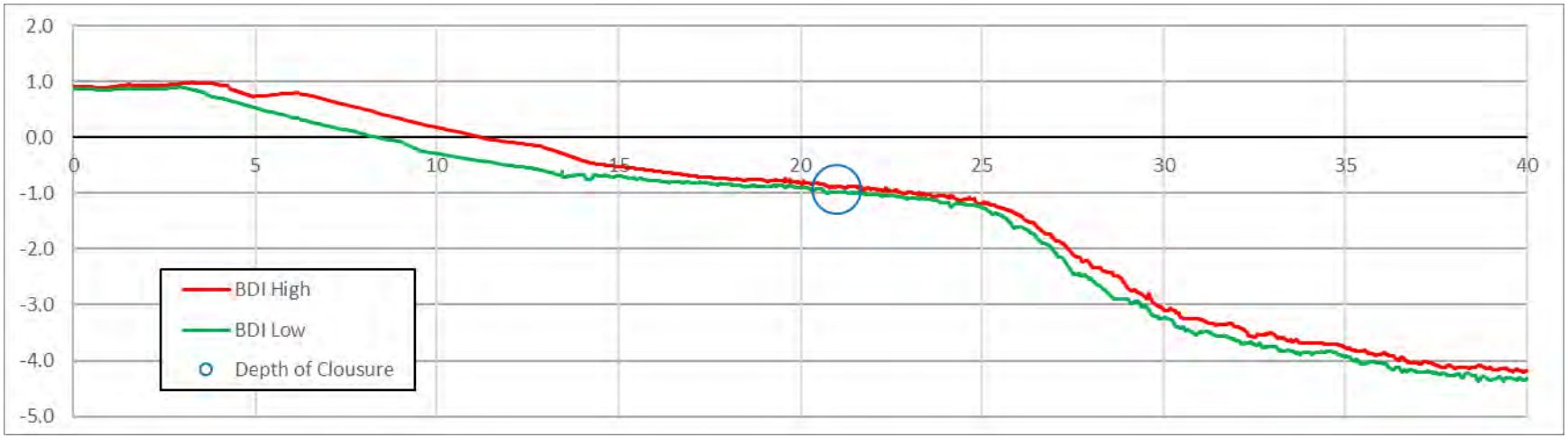

Figure J-51. Envelope of beach profiles and depth of closure at Beach 5 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

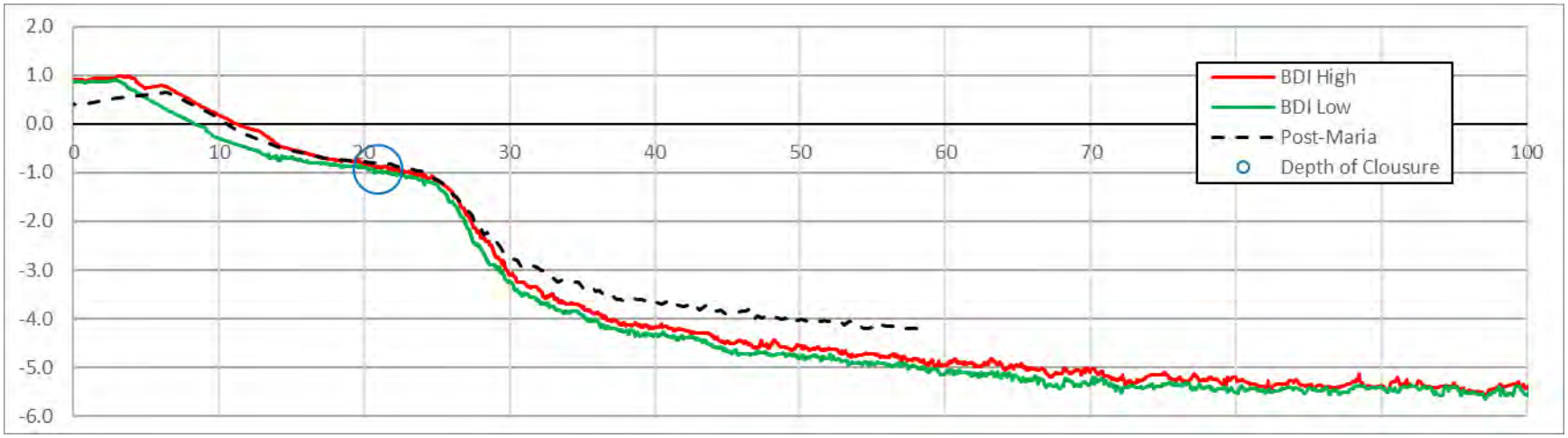

Figure J-52. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 5 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

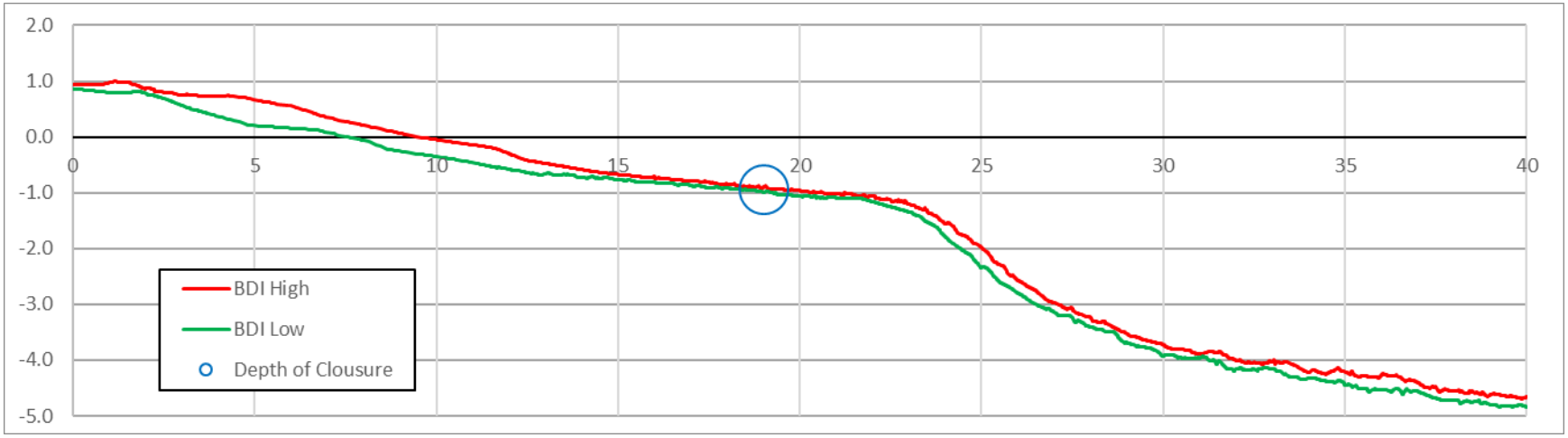

Figure J-53. Envelope of beach profiles and depth of closure at Beach 5 transect 6, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

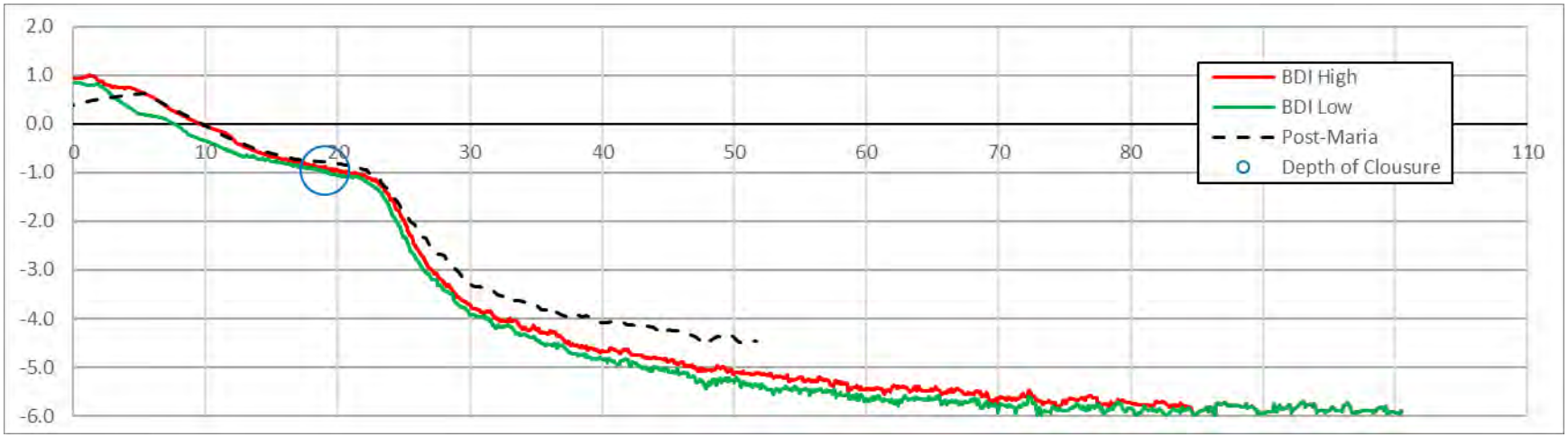

Figure J-54. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 5 transect 6, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

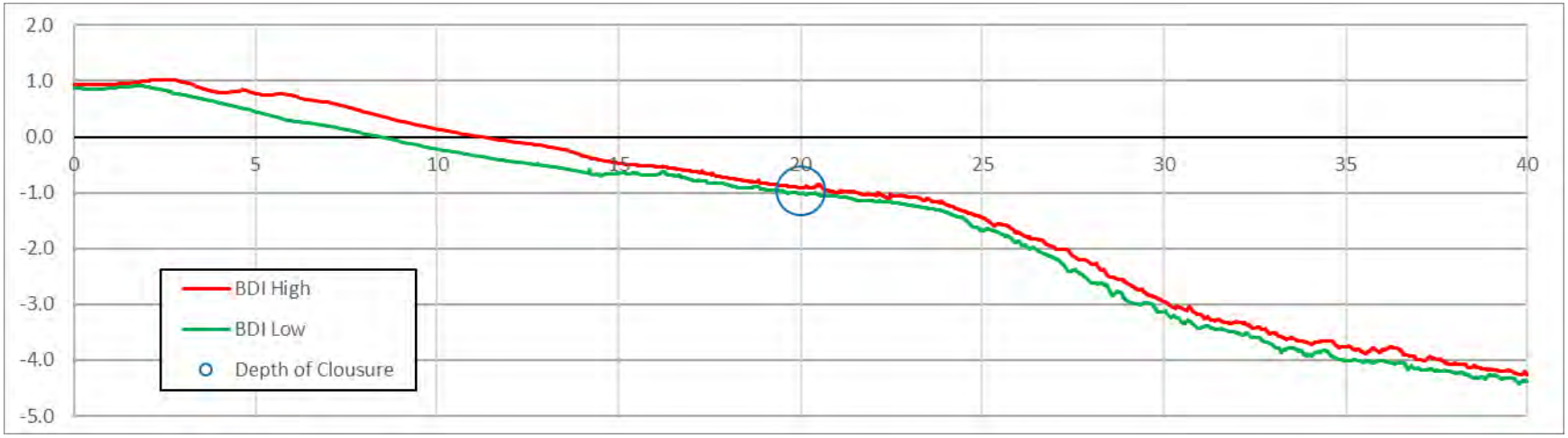

Figure J-55. Envelope of beach profiles and depth of closure at Beach 5 transect 7, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

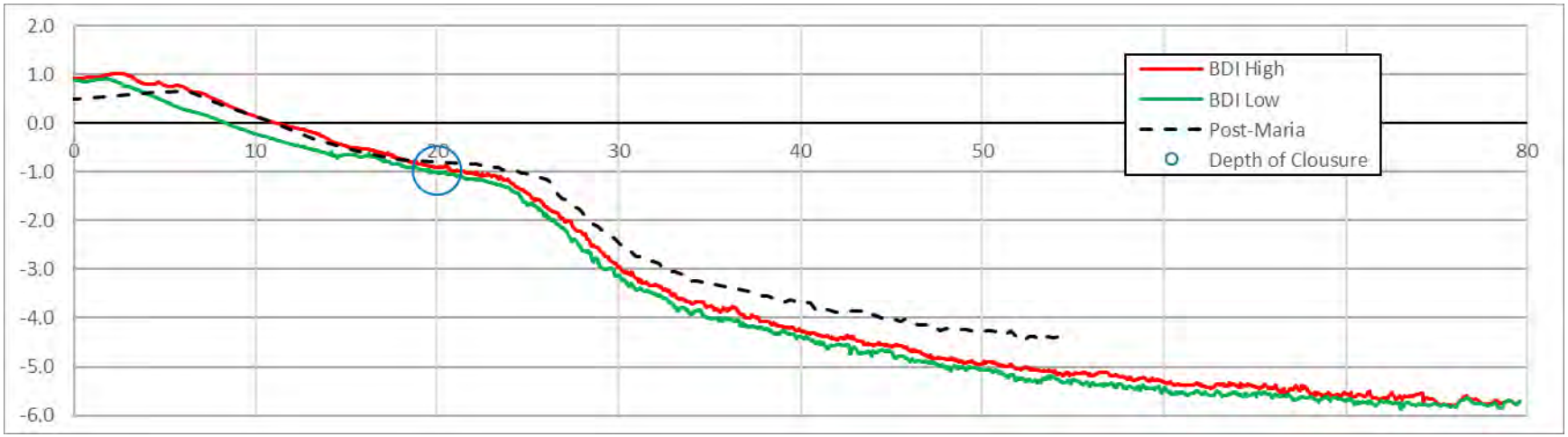

Figure J-56. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 5 transect 7, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Figure J-57. Envelope of beach profiles and depth of closure at Beach 5 transect 8, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

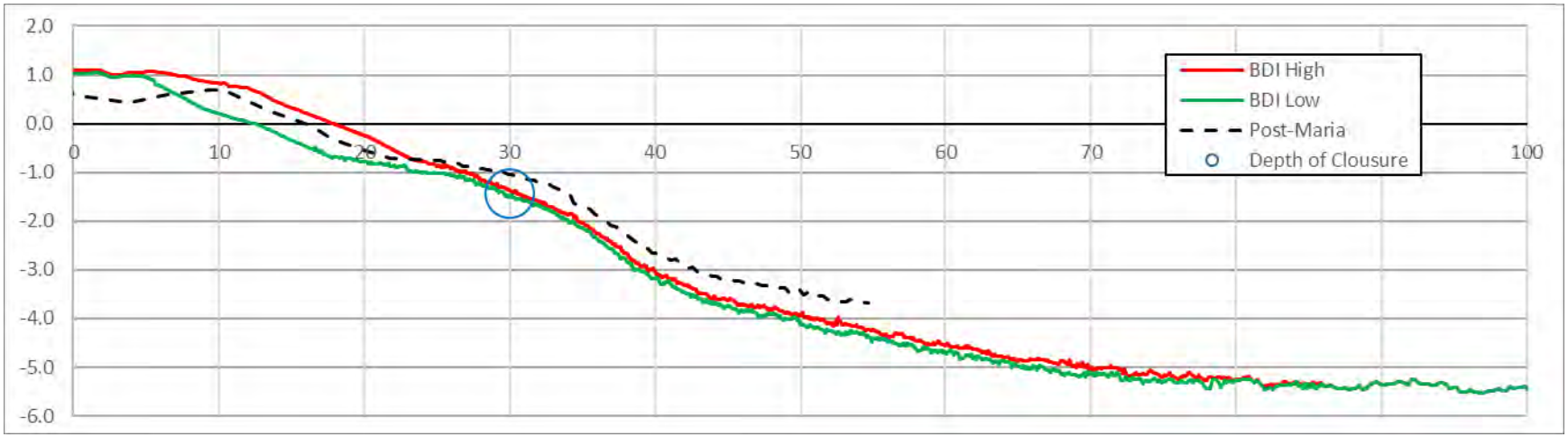

Figure J-58. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 5 transect 8, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

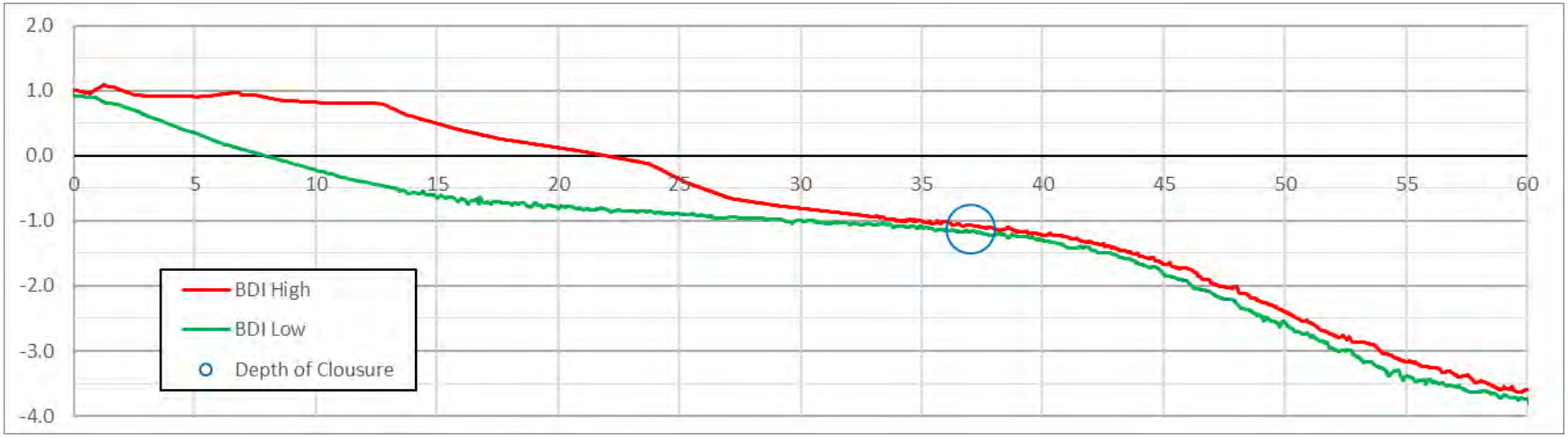

Figure J-59. Envelope of beach profiles and depth of closure at Beach 5 transect 9, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

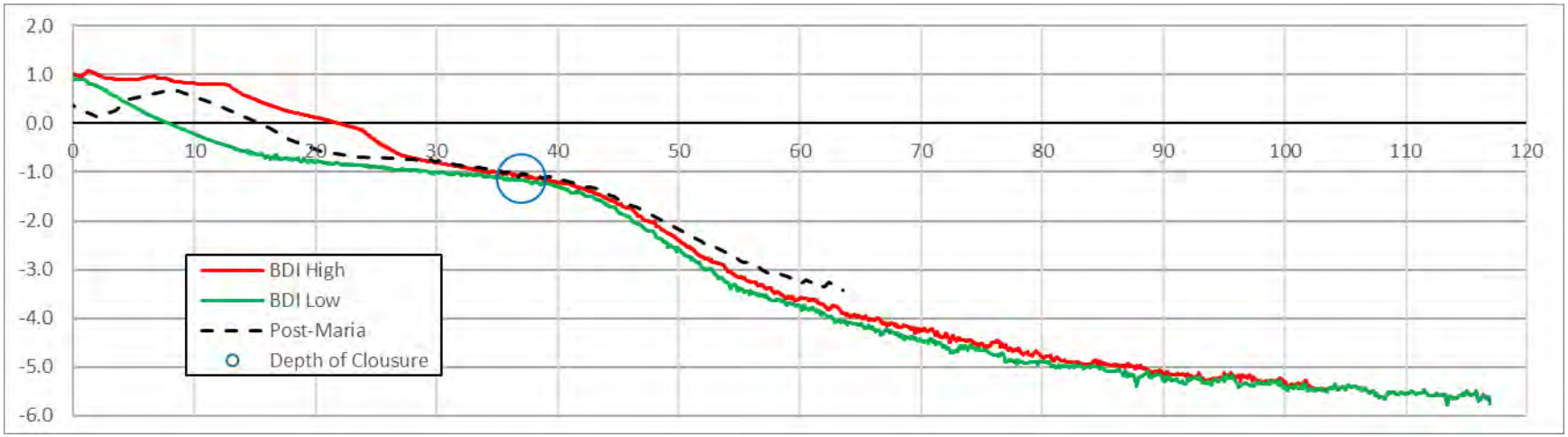

Figure J-60. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 5 transect 9, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

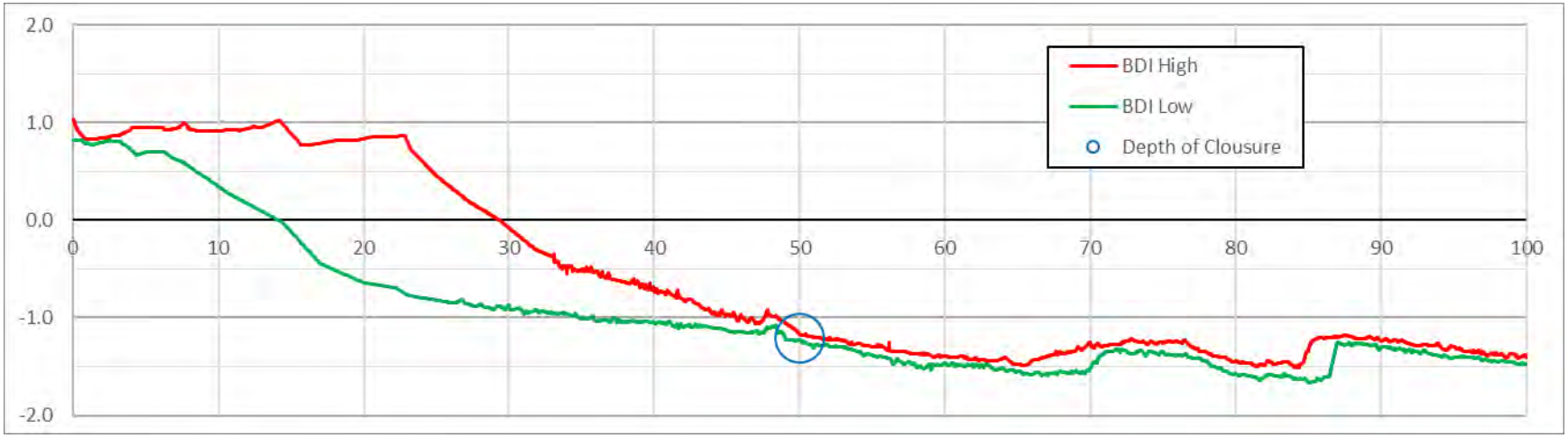

Figure J-61. Envelope of beach profiles and depth of closure at Beach 5 transect 10, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

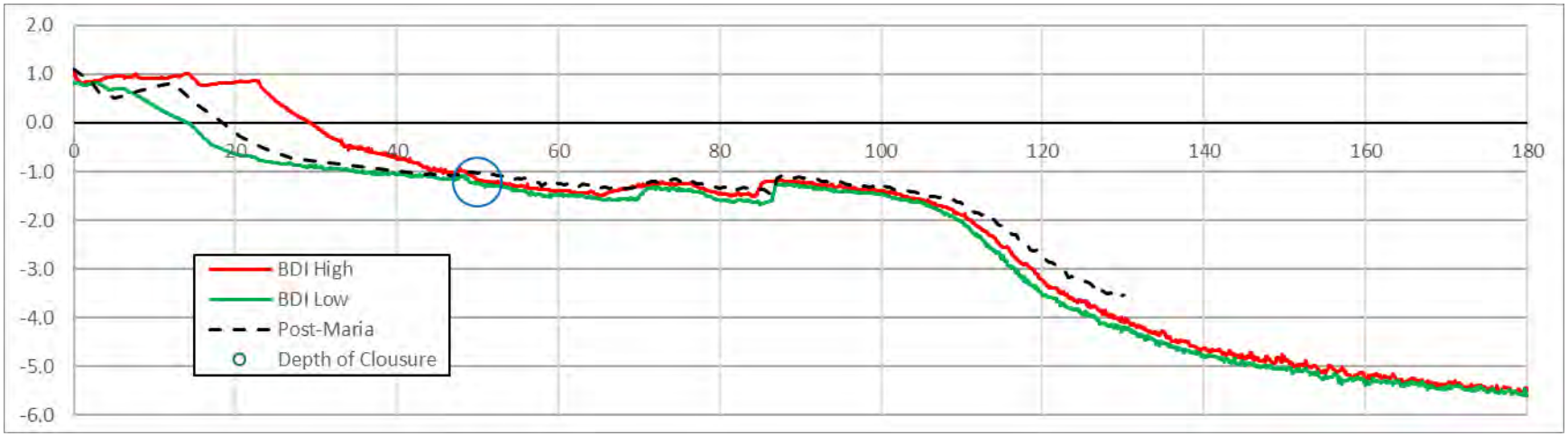

Figure J-62. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 5 transect 10, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Table J-7. Locations of depth of closure and landward limit of beach change, and width of area of beach change during the BDI and Post-Maria for Beach 5.

Transect	Depth of Closure			Landward Limit of Beach Change						Width	
				BDI			Post-Maria				
	Easting	Northing	BDI	BDI	Northing	Elevation	Easting	Northing	Elevation	BDI	Post-Maria
05-01	256,499.9	2,007,546.8	-0.95	256,519.0	2,007,544.0	0.68	256,523.9	2,007,543.3	0.78	19.3	24.3
05-02	256,492.0	2,007,456.6	-0.89	256,507.6	2,007,443.9	0.71	256,509.8	2,007,442.1	0.65	20.2	23.0
05-03	256,449.6	2,007,421.4	-0.88	256,457.5	2,007,407.1	0.81	256,459.2	2,007,403.9	0.70	16.4	20.0
05-04	256,393.7	2,007,401.8	-1.04	256,398.5	2,007,384.7	0.78	256,400.5	2,007,377.7	0.80	17.8	25.0
05-05	256,276.1	2,007,400.0	-0.93	256,274.0	2,007,382.7	0.89	256,273.0	2,007,374.2	0.90	17.4	26.0
05-06	256,159.9	2,007,429.2	-0.95	256,153.7	2,007,413.8	0.70	256,151.3	2,007,407.9	0.90	16.6	23.0
05-07	256,051.8	2,007,481.9	-0.96	256,042.4	2,007,466.6	0.93	256,039.5	2,007,461.9	0.90	17.9	23.5
05-08	255,962.2	2,007,559.2	-1.43	255,944.6	2,007,541.2	1.04	255,940.0	2,007,536.5	1.00	25.2	31.7
05-09	255,891.9	2,007,658.6	-1.13	255,864.3	2,007,635.1	0.91	255,862.8	2,007,633.8	0.94	36.3	38.3
05-10	255,822.7	2,007,757.5	-1.20	255,785.1	2,007,729.3	0.85	255,782.6	2,007,727.5	1.10	19.3	50.0

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
Depth of closure and elevations of landward limit of beach change relative to PRVD02
Width (of the area of beach change) = horizontal distance along the transect between the depth of closure and landward limit of beach change

Table J-8. Locations of maximum beach elevation change, ranges, and high and low elevations of envelope for Beach 5.

Transect	Easting	Northing	Range	High	Low
05-01	256,512.4	2,007,545.0	0.33	0.01	-0.32
05-02	256,504.6	2,007,446.3	0.41	0.29	-0.11
05-03	256,457.0	2,007,408.0	0.54	0.92	0.37
05-04	256,397.6	2,007,388.1	0.59	0.51	-0.07
05-05	256,274.7	2,007,388.6	0.49	0.25	-0.24
05-06	256,154.6	2,007,416.1	0.48	0.70	0.22
05-07	256,044.5	2,007,470.0	0.46	0.74	0.29
05-08	255,953.0	2,007,549.8	0.71	0.11	-0.60
05-09	255,873.6	2,007,643.0	1.25	0.78	-0.47
05-10	255,800.9	2,007,741.2	1.62	0.87	-0.75

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
High and low elevations relative to PRVD02

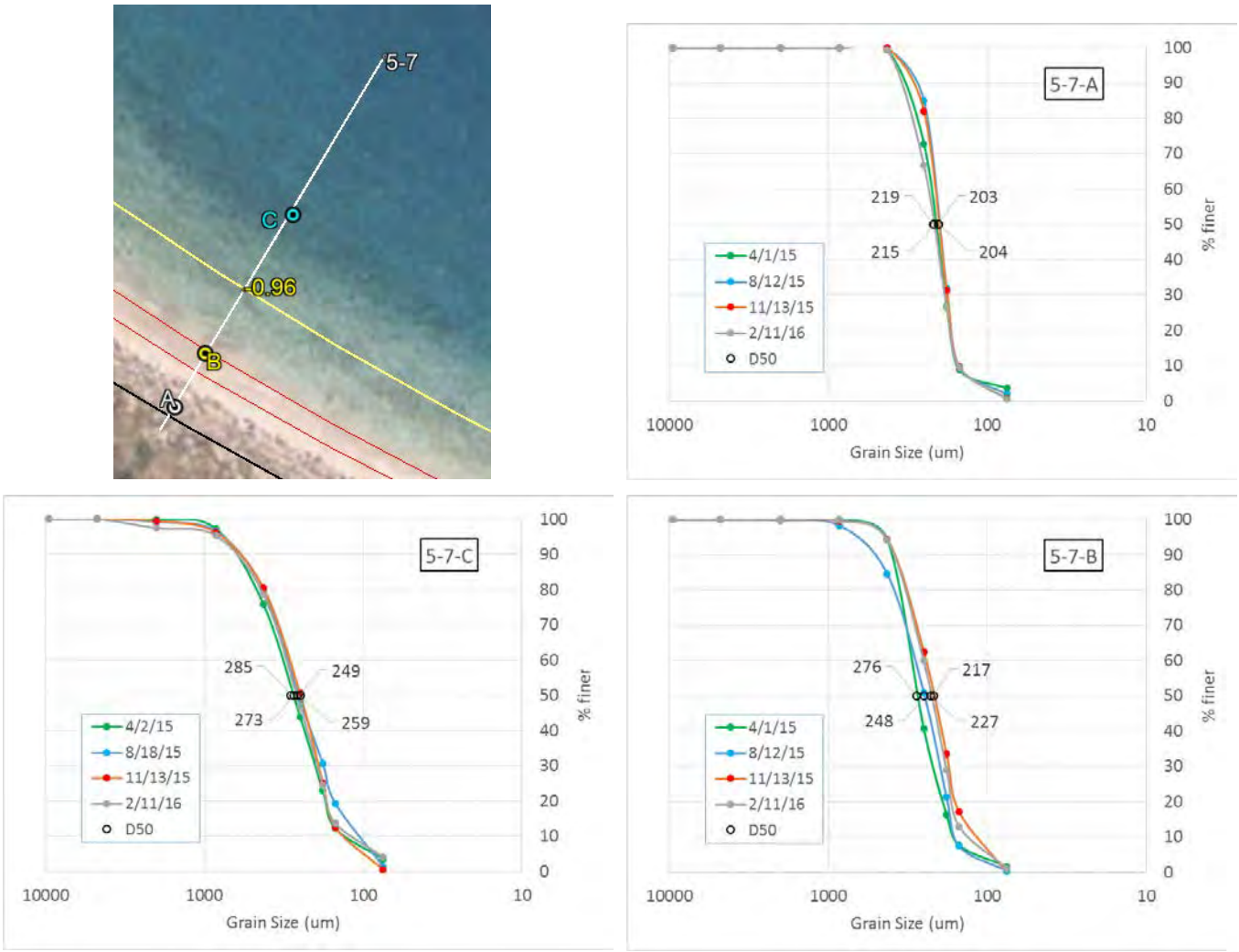

Figure J-63. Clockwise from top: approximate locations of sediment samples at Beach 5, BDI landward limit of beach change, maximum landward and seaward shoreline positions, depth of closure; and distribution of grain size at backshore (A), shoreline (B) and nearshore (C) locations.

LIA UXO 2
Beach 12

Figure J-64. Beach 12 transects, bathymetry and coastal features.

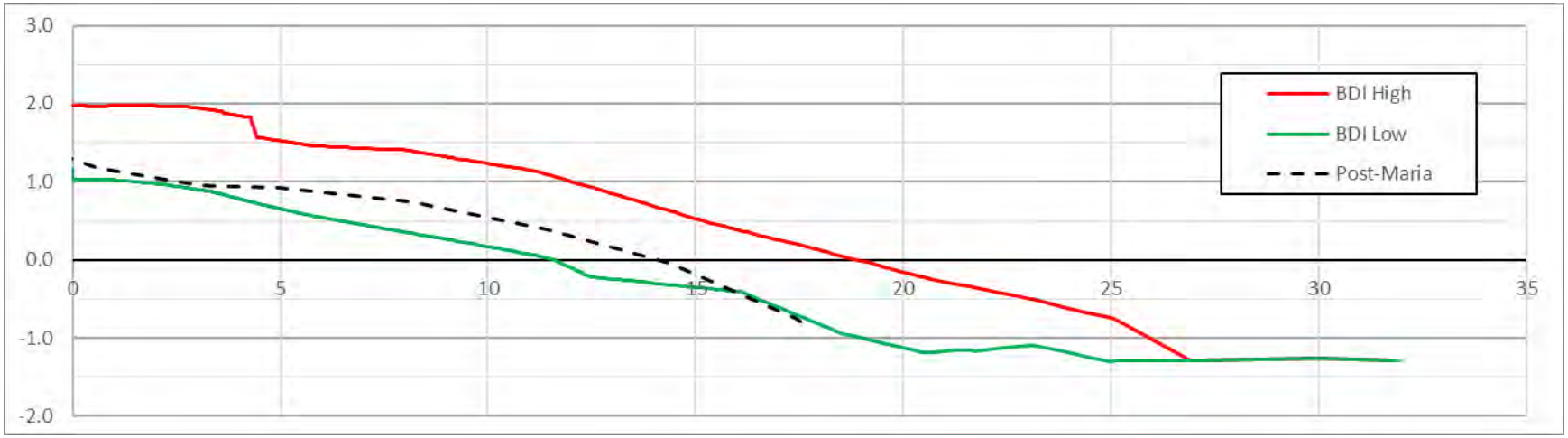

Figure J-65. Envelope of beach profiles and post-Maria profile at Beach 12 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

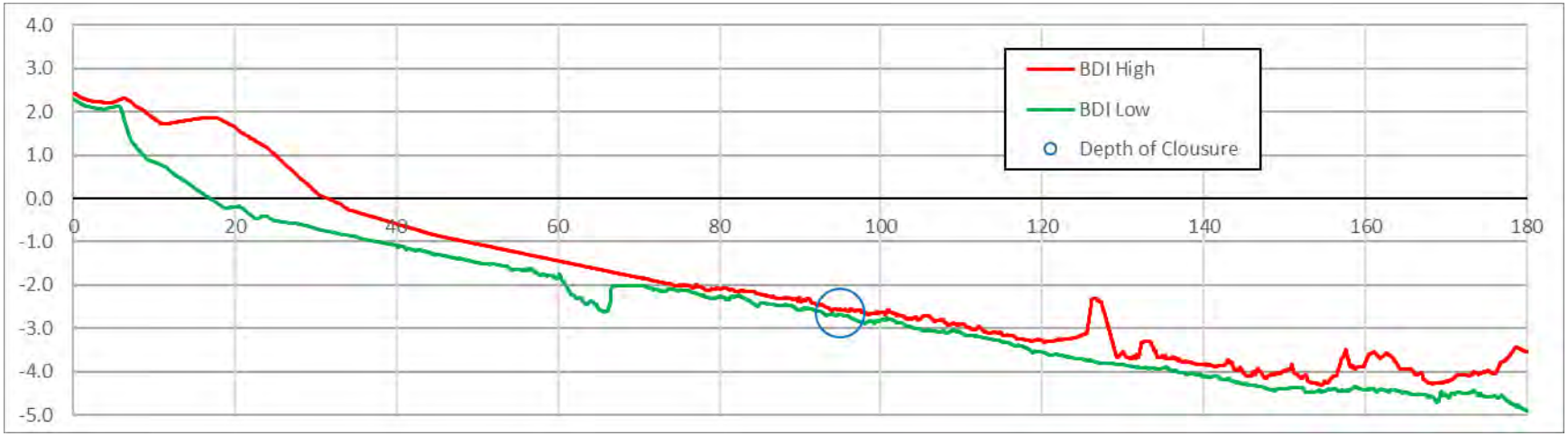

Figure J-66. Envelope of beach profiles and depth of closure at Beach 12 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

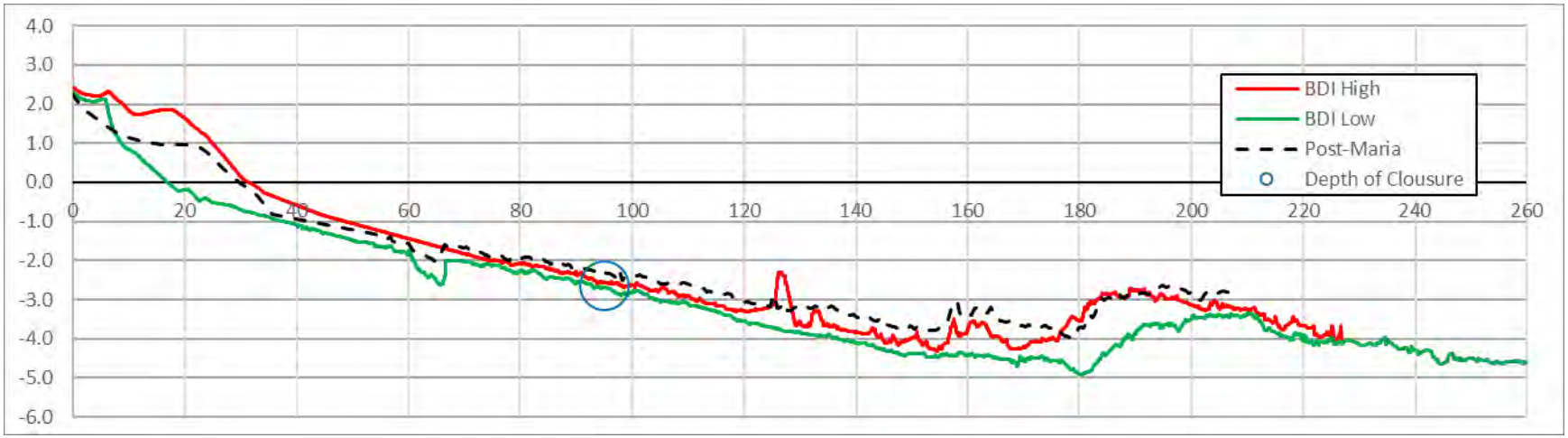

Figure J-67. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 12 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

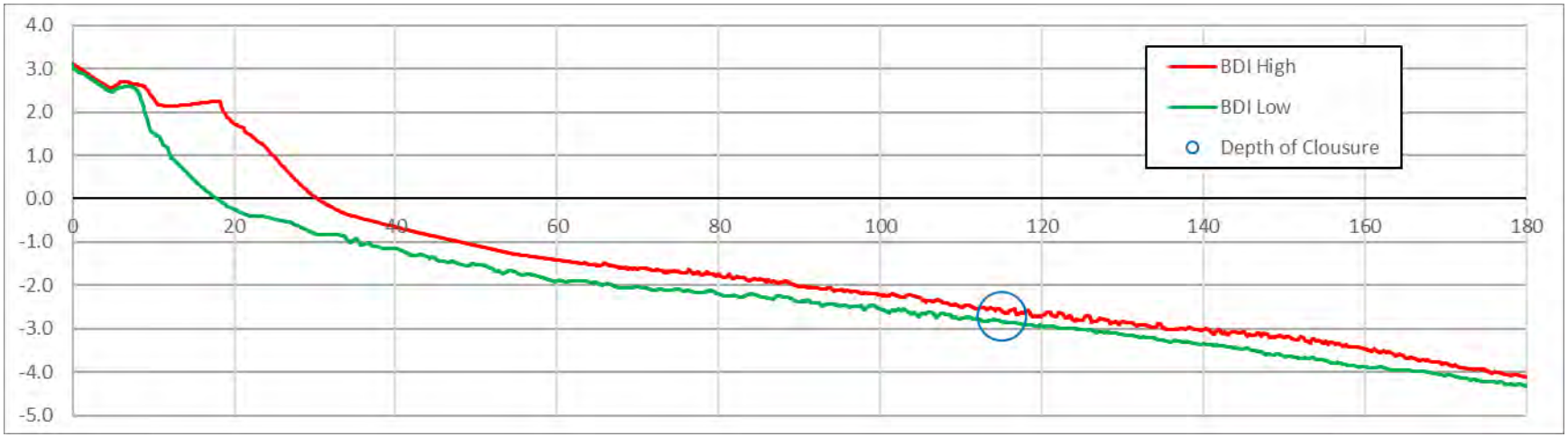

Figure J-68. Envelope of beach profiles and depth of closure at Beach 12 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

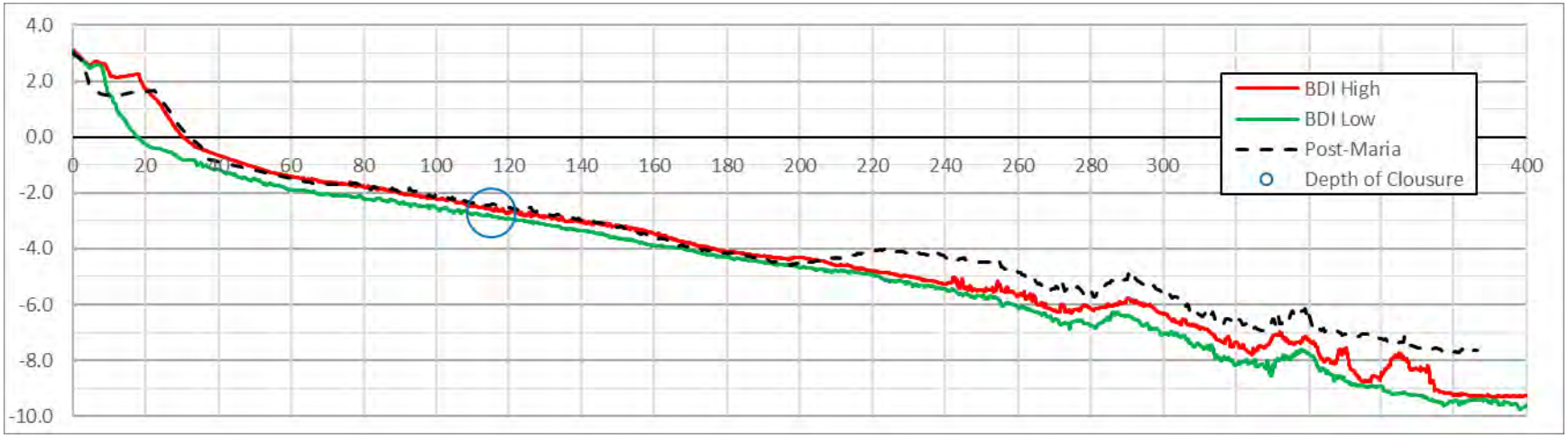

Figure J-69. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 12 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

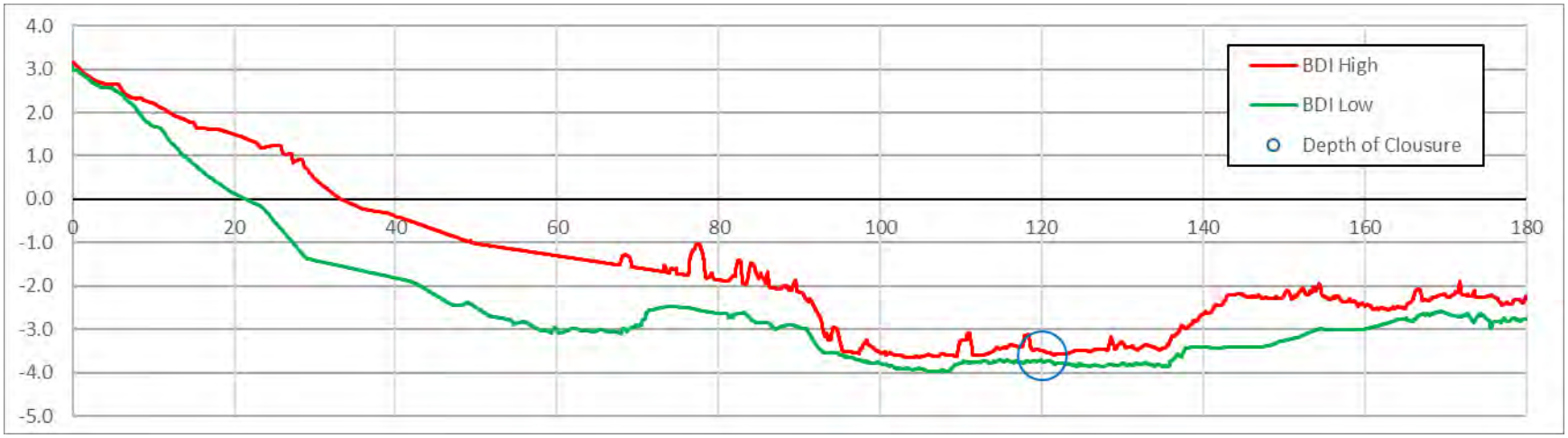

Figure J-70. Envelope of beach profiles and depth of closure at Beach 12 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

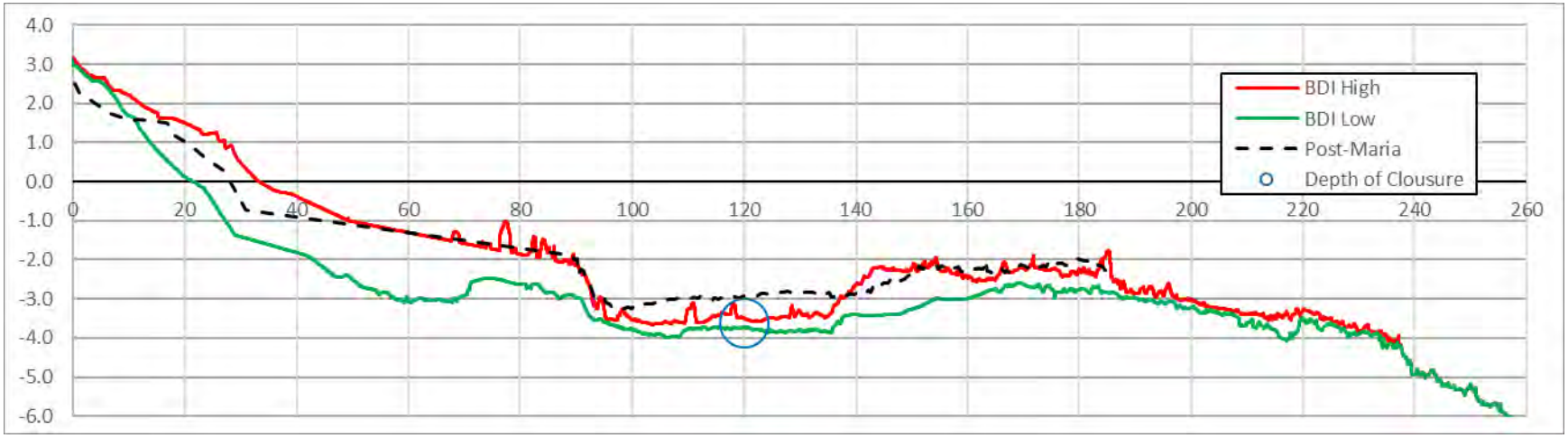

Figure J-71. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 12 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Table J-9. Locations of depth of closure and landward limit of beach change, and width of area of beach change during the BDI and Post-Maria for Beach 12.

Transect	Depth of Closure			Landward Limit of Beach Change						Width	
				BDI			Post-Maria				
	Easting	Northing	Depth	Easting	Northing	Elevation	Easting	Northing	Elevation	BDI	Post-Maria
12-01				258,220.8	2,007,637.4	1.66	258,220.8	2,007,637.4	1.39		
12-02	258,195.8	2,007,735.2	-2.64	258,153.4	2,007,656.6	2.17	258,150.7	2,007,651.6	2.28	89.3	95.0
12-03	258,174.1	2,007,769.2	-2.72	258,119.3	2,007,678.4	2.23	258,116.0	2,007,672.9	2.74	106.0	112.5
12-04	258,127.5	2,007,812.7	-3.61	258,046.2	2,007,733.1	2.46	258,040.4	2,007,727.4	3.00	113.9	122.0

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
Depth of closure and elevations of landward limit of beach change relative to PRVD02
Width (of the area of beach change) = horizontal distance along the transect between the depth of closure and landward limit of beach change

Table J-10. Locations of maximum beach elevation change, ranges, and high and low elevations of envelope for Beach 12.

Transect	Easting	Northing	Range	High	Low
12-01	258,220.9	2,007,649.8	1.15	0.93	-0.22
12-02	258,159.7	2,007,668.1	2.00	1.77	-0.23
12-03	258,124.1	2,007,686.4	2.30	2.25	-0.05
12-04	258,062.2	2,007,748.7	2.17	0.90	-1.27

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
High and low elevations relative to PRVD02

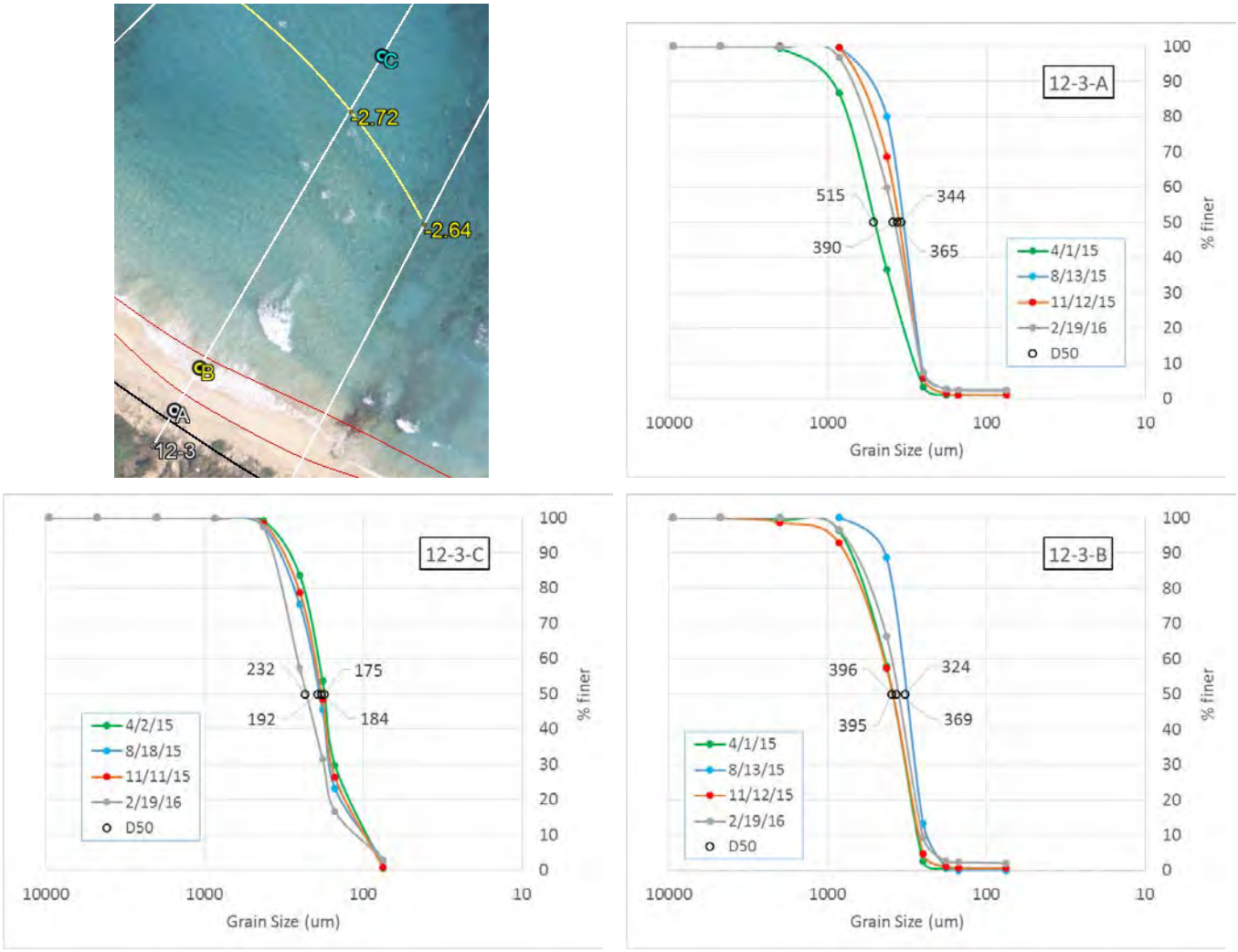

Figure J-72. Clockwise from top: approximate locations of sediment samples at Beach 12, BDI landward limit of beach change, maximum landward and seaward shoreline positions, depth of closure; and distribution of grain size at backshore (A), shoreline (B) and nearshore (C) locations.

LIA UXO 2
Beach 14

Figure J-73. Beach 14 transects, bathymetry and coastal features.

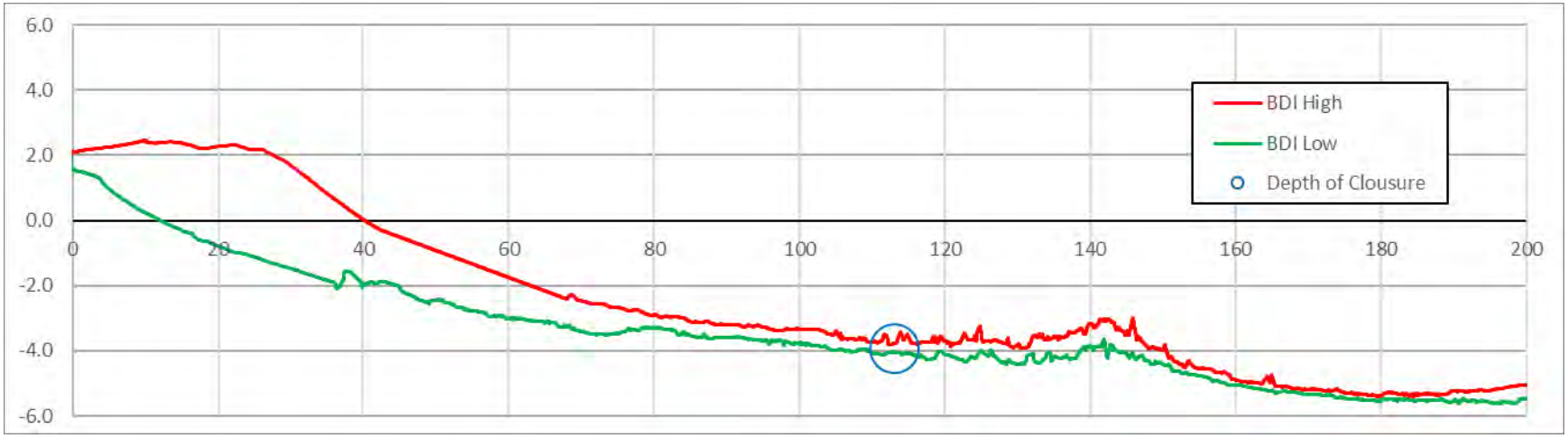

Figure J-74. Envelope of beach profiles and depth of closure at Beach 14 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

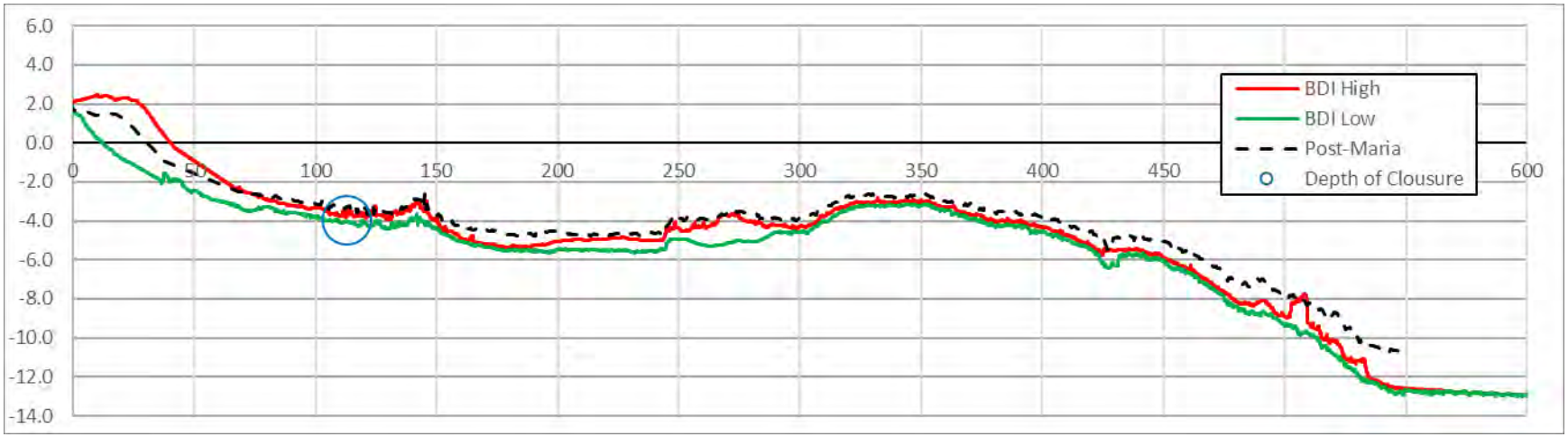

Figure J-75. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 14 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

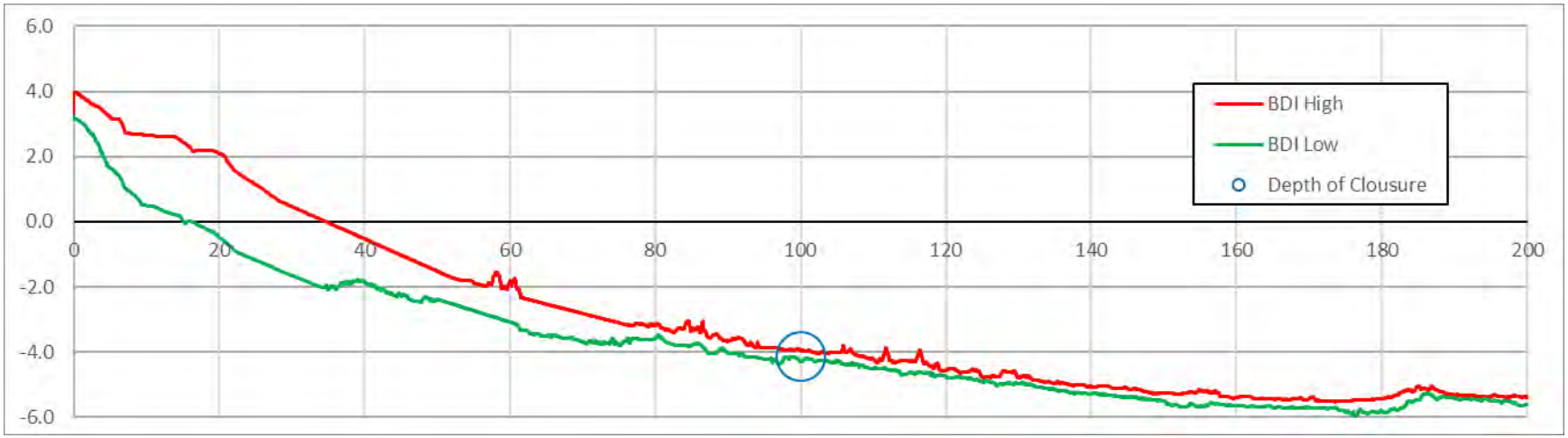

Figure J-76. Envelope of beach profiles and depth of closure at Beach 14 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

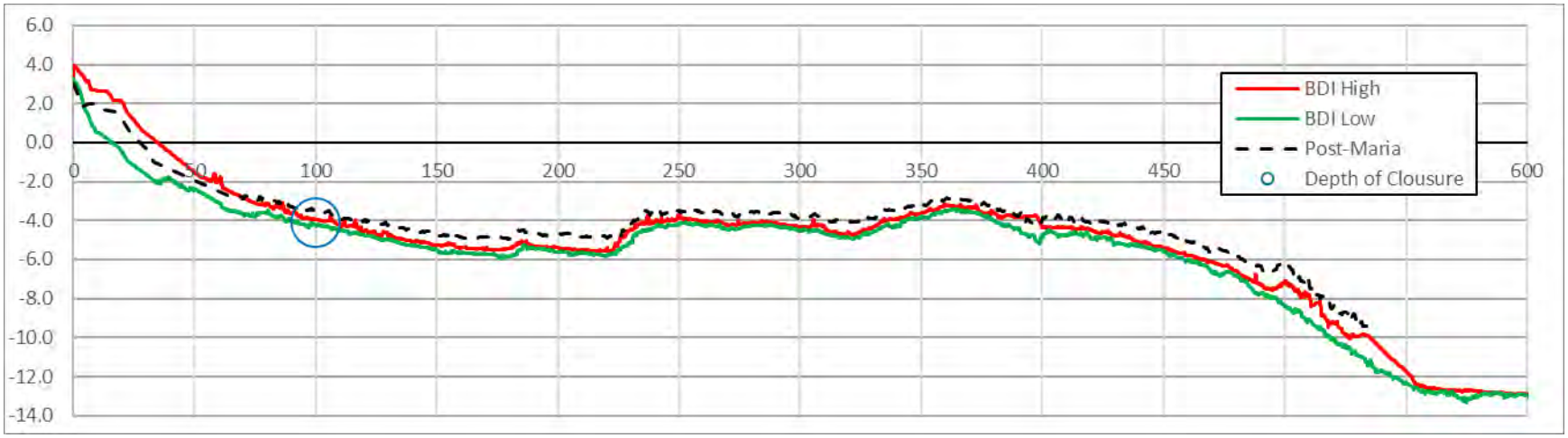

Figure J-77. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 14 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

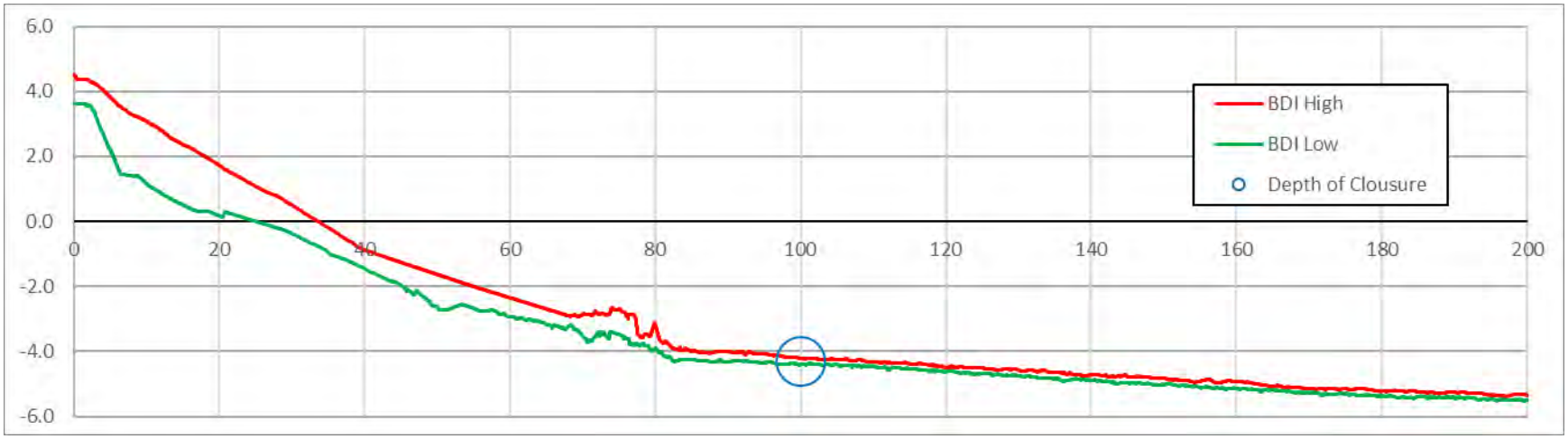

Figure J-78. Envelope of beach profiles and depth of closure at Beach 14 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

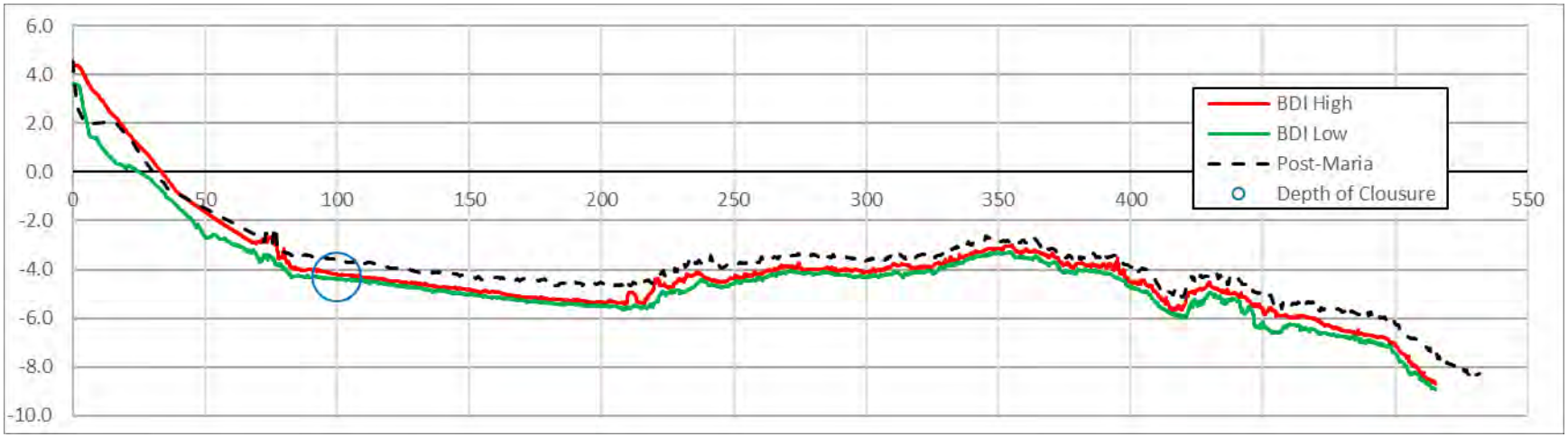

Figure J-79. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 14 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

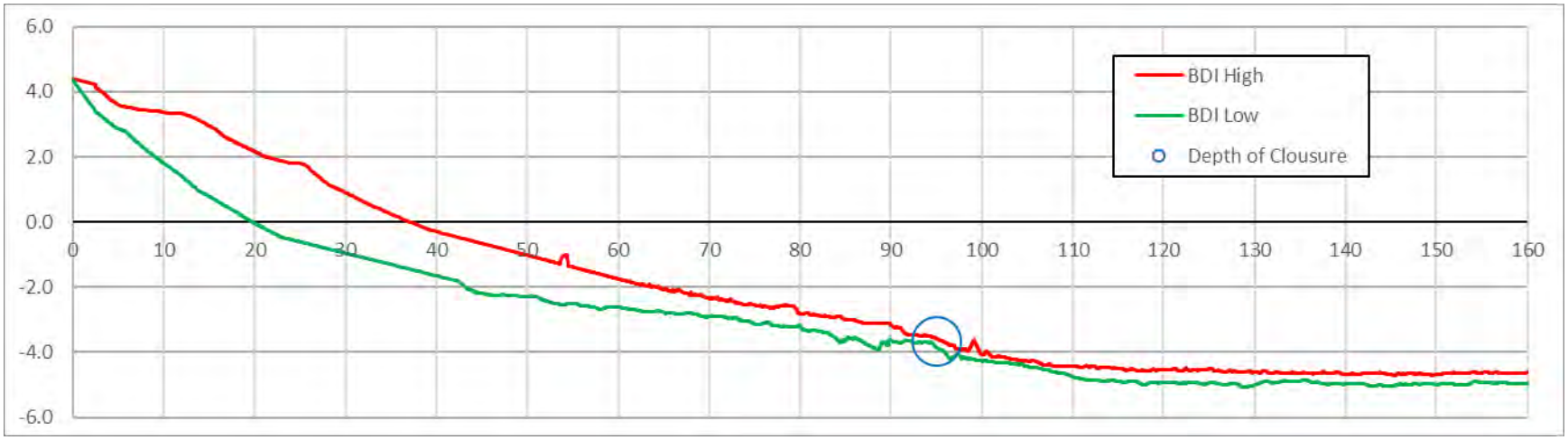

Figure J-80. Envelope of beach profiles and depth of closure at Beach 14 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

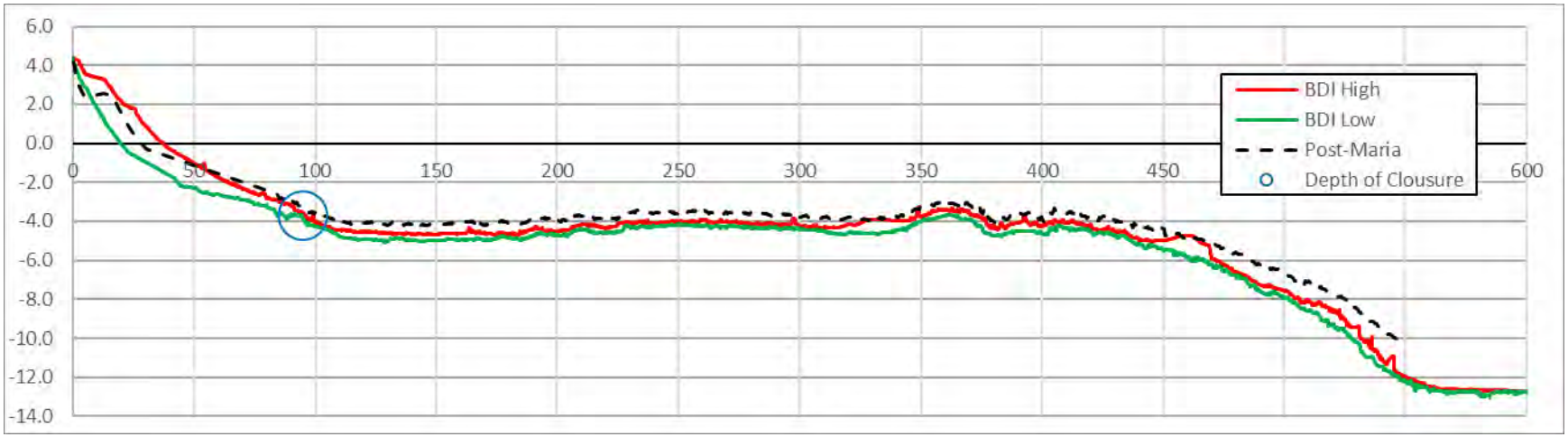

Figure J-81. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 14 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

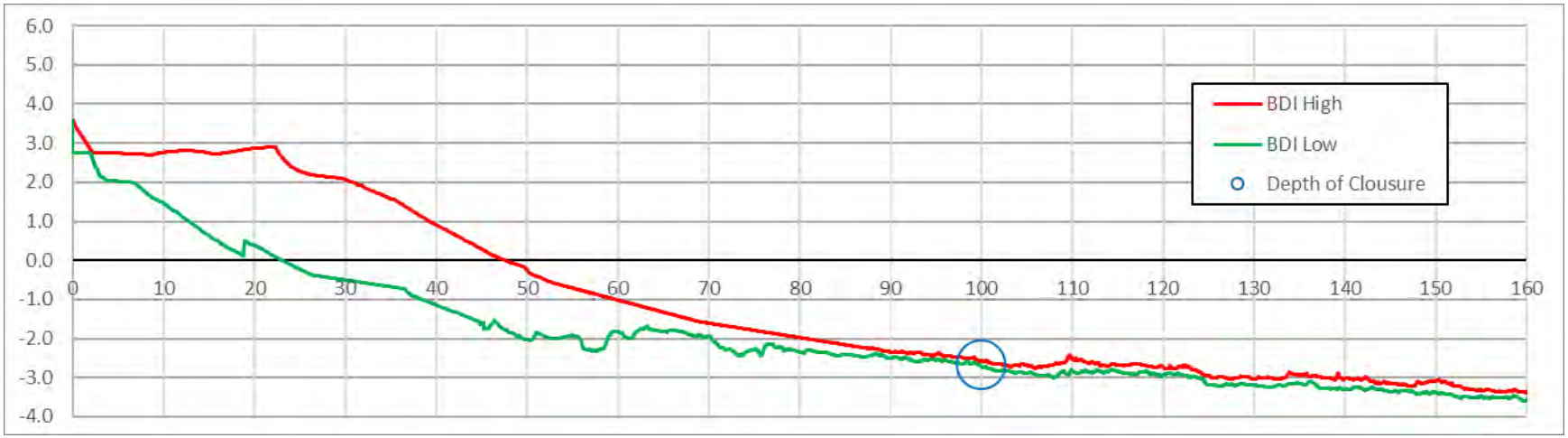

Figure J-82. Envelope of beach profiles and depth of closure at Beach 14 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

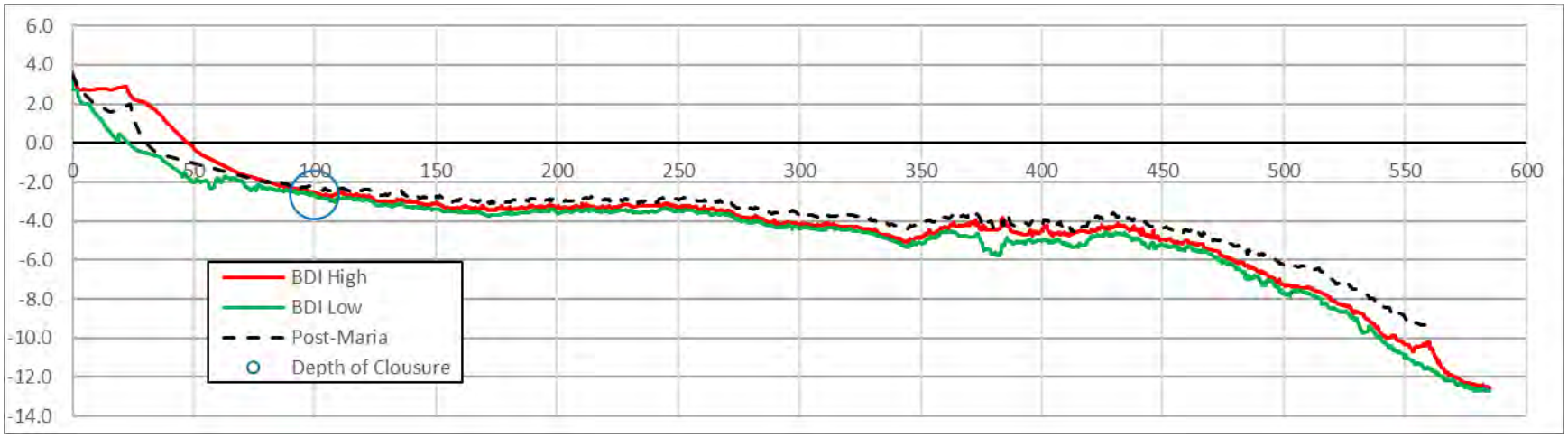

Figure J-83. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 14 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Table J-11. Locations of depth of closure and landward limit of beach change, and width of area of beach change during the BDI and Post-Maria for Beach 14.

Transect	Depth of Closure			Landward Limit of Beach Change						Width	
				BDI			Post-Maria				
	Easting	Northing	Depth	Easting	Northing	Elevation	Easting	Northing	Elevation	BDI	Post-Maria
14-01	258,864.0	2,007,168.7	-3.95	258,768.9	2,007,107.7	2.05	258,766.7	2,007,106.3	2.02	113.0	115.6
14-02	258,811.7	2,007,220.9	-4.12	258,726.3	2,007,173.4	2.73	258,723.4	2,007,171.8	3.30	97.7	101.0
14-03	258,775.0	2,007,276.7	-4.29	258,684.8	2,007,234.5	4.27	258,684.4	2,007,234.3	4.56	99.6	100.0
14-04	258,742.8	2,007,338.8	-3.68	258,655.1	2,007,306.4	4.00	258,654.3	2,007,306.1	3.88	93.5	94.4
14-05	258,722.4	2,007,404.4	-2.65	258,629.1	2,007,377.5	2.53	258,626.9	2,007,376.8	3.23	97.1	99.4

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
Depth of closure and elevations of landward limit of beach change relative to PRVD02
Width (of the area of beach change) = horizontal distance along the transect between the depth of closure and landward limit of beach change

Table J-12. Locations of maximum beach elevation change, ranges, and high and low elevations of envelope for Beach 14.

Transect	Easting	Northing	Range	High	Low
14-01	258,791.0	2,007,121.8	3.37	2.16	-1.21
14-02	258,742.4	2,007,182.3	2.62	2.03	-0.59
14-03	258,690.3	2,007,237.1	2.08	3.53	1.45
14-04	258,676.9	2,007,314.5	2.41	1.82	-0.59
14-05	258,647.7	2,007,382.8	2.81	2.90	0.09

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
High and low elevations relative to PRVD02

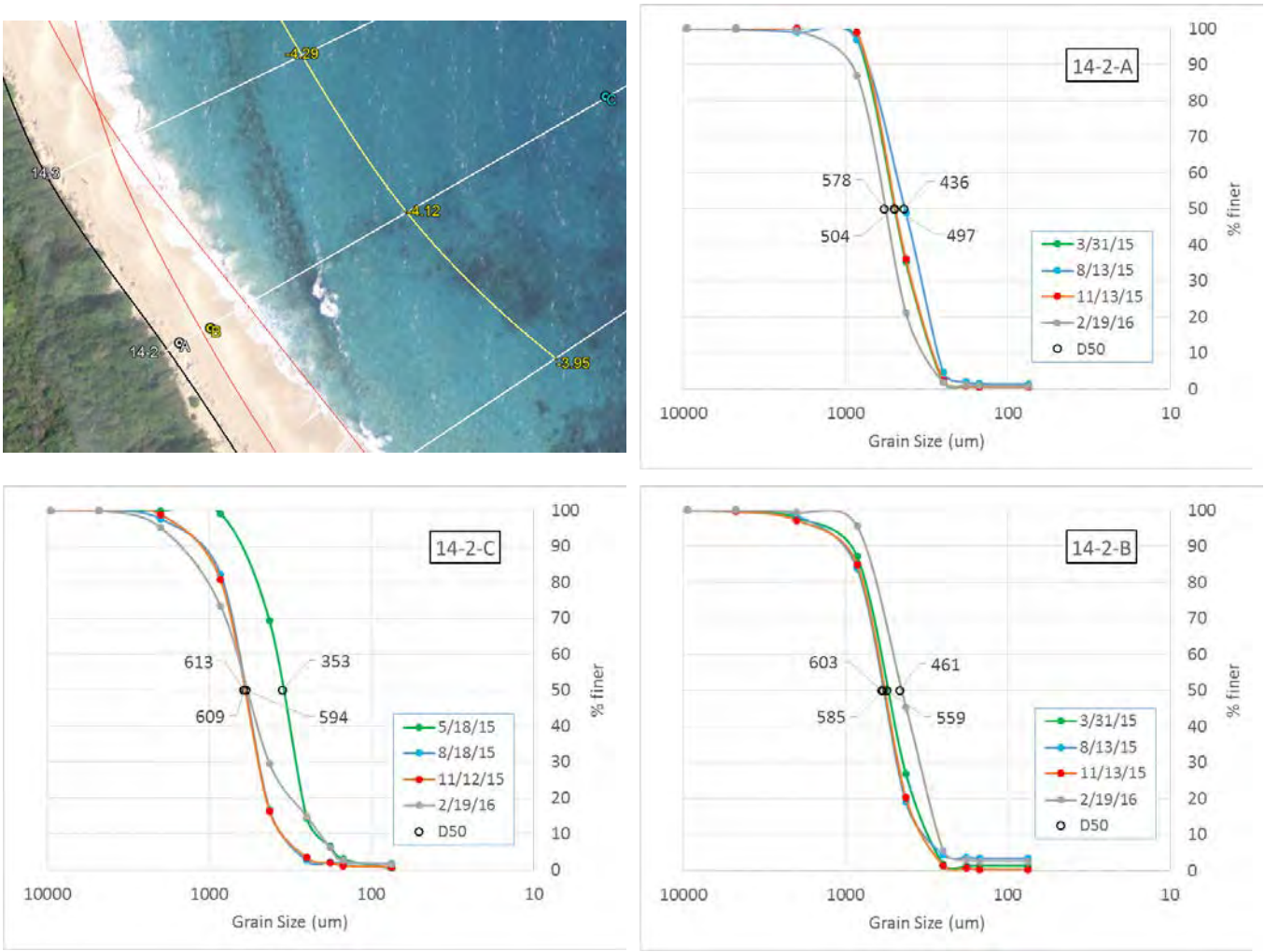

Figure J-84. Clockwise from top: approximate locations of sediment samples at Beach 14, BDI landward limit of beach change, maximum landward and seaward shoreline positions, depth of closure; and distribution of grain size at backshore (A), shoreline (B) and nearshore (C) locations.

North EMA and SIA UXO 7
Beach 22

Figure J-85. Beach 22 transects, bathymetry and coastal features.

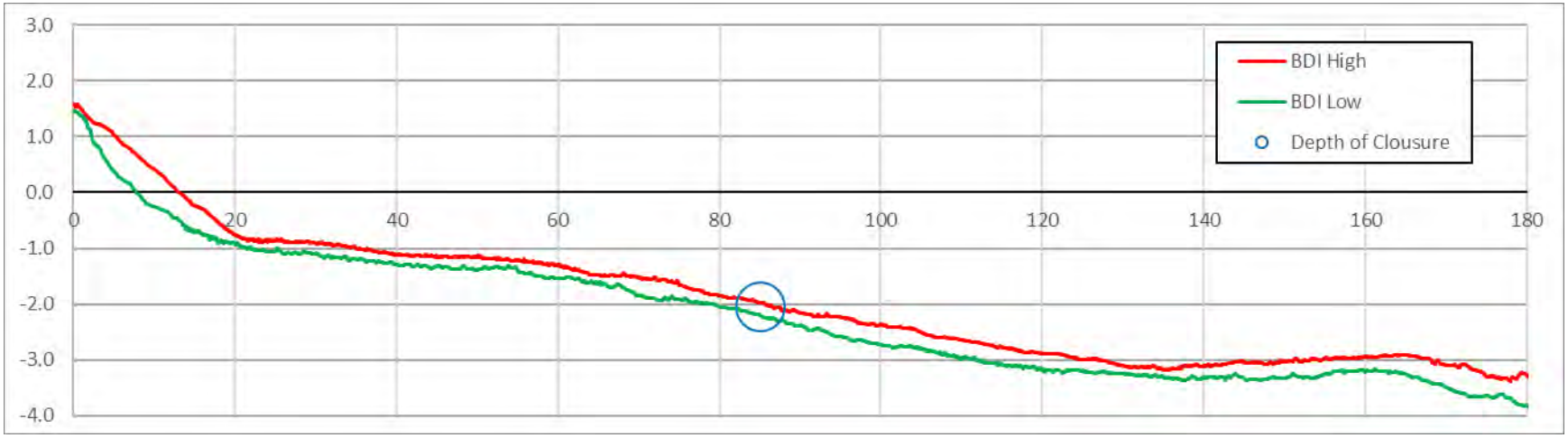

Figure J-86. Envelope of beach profiles and depth of closure at Beach 22 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

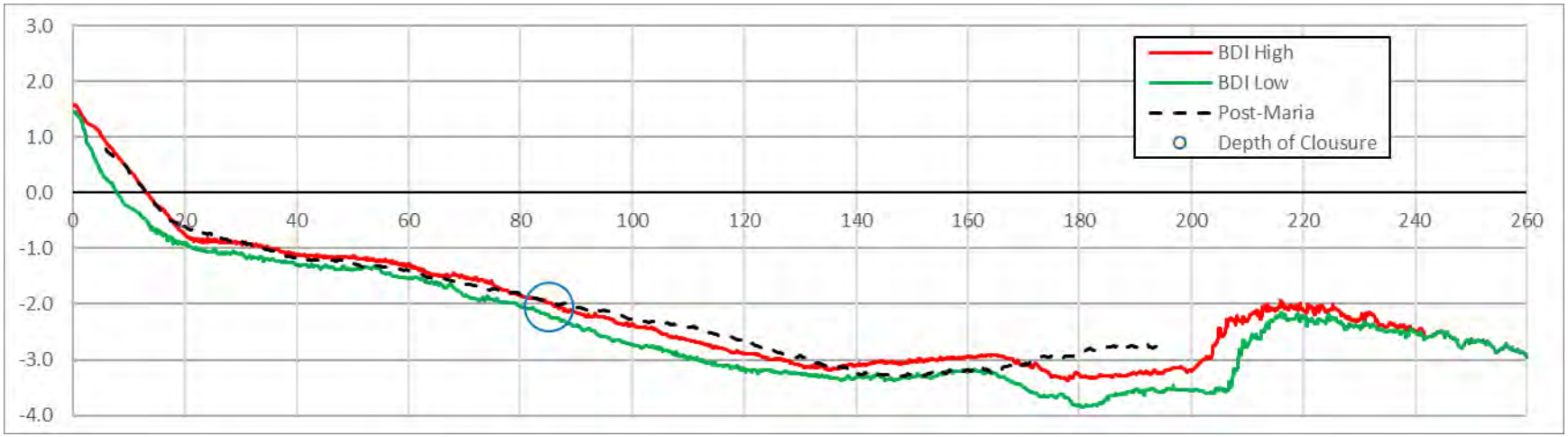

Figure J-87. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 22 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

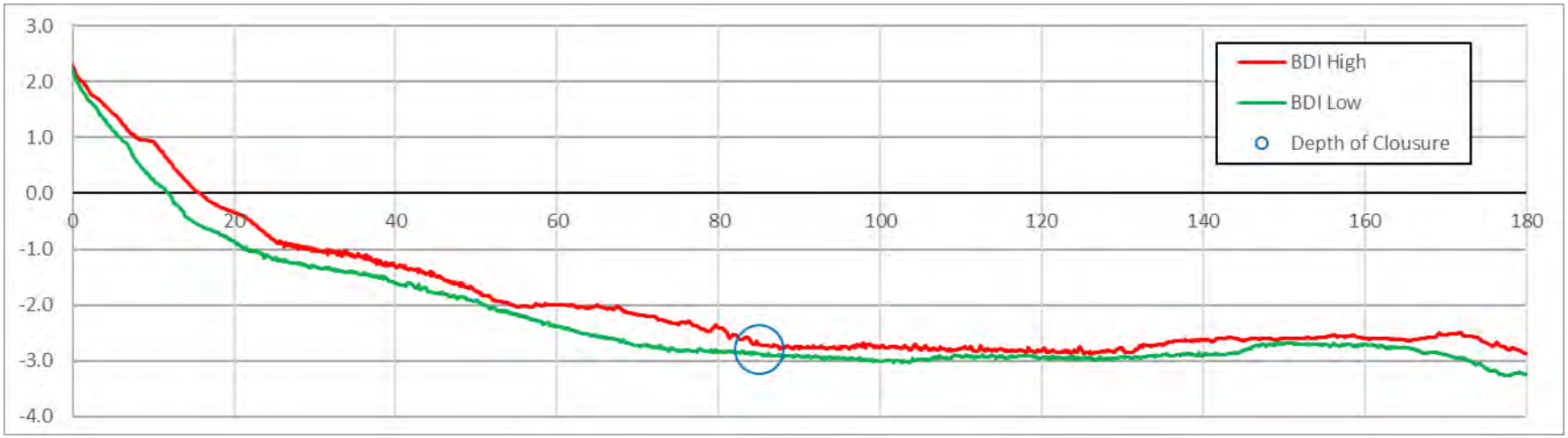

Figure J-88. Envelope of beach profiles and depth of closure at Beach 22 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

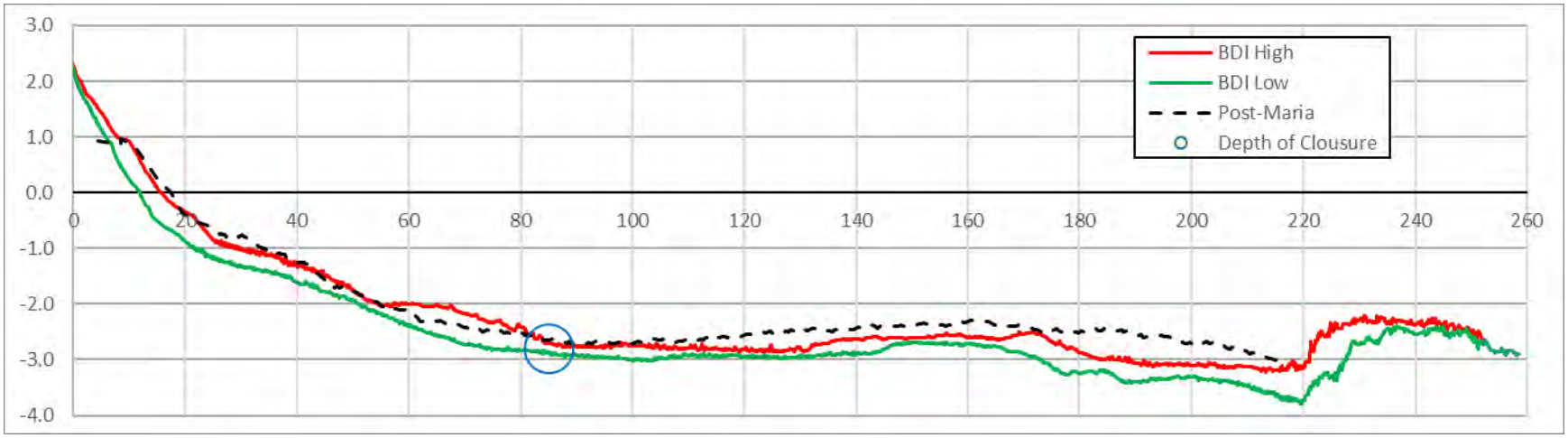

Figure J-89. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 22 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

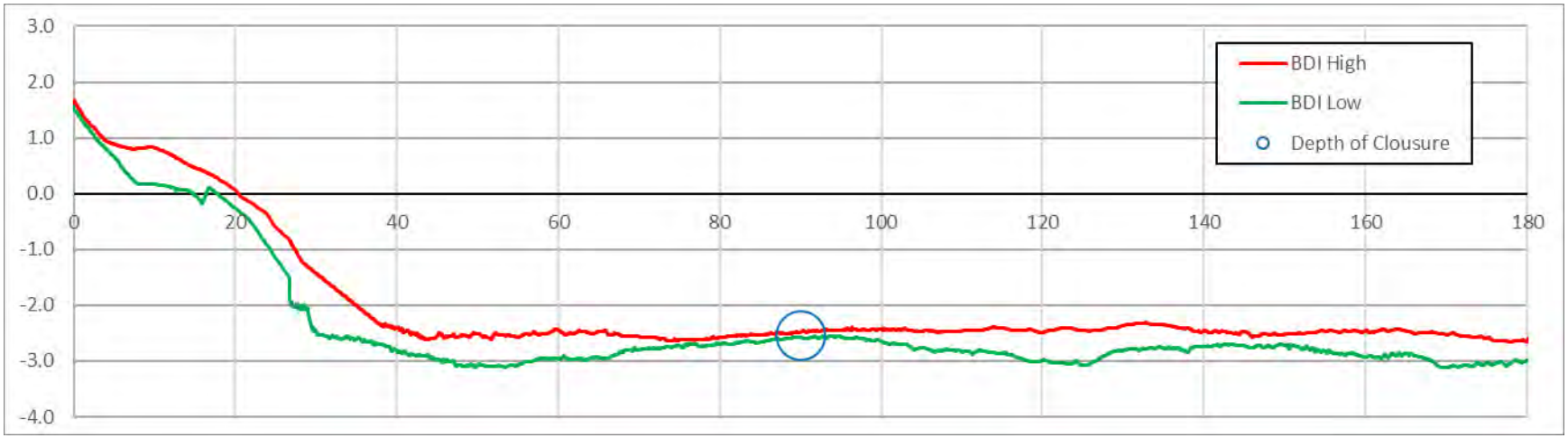

Figure J-90. Envelope of beach profiles and depth of closure at Beach 22 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

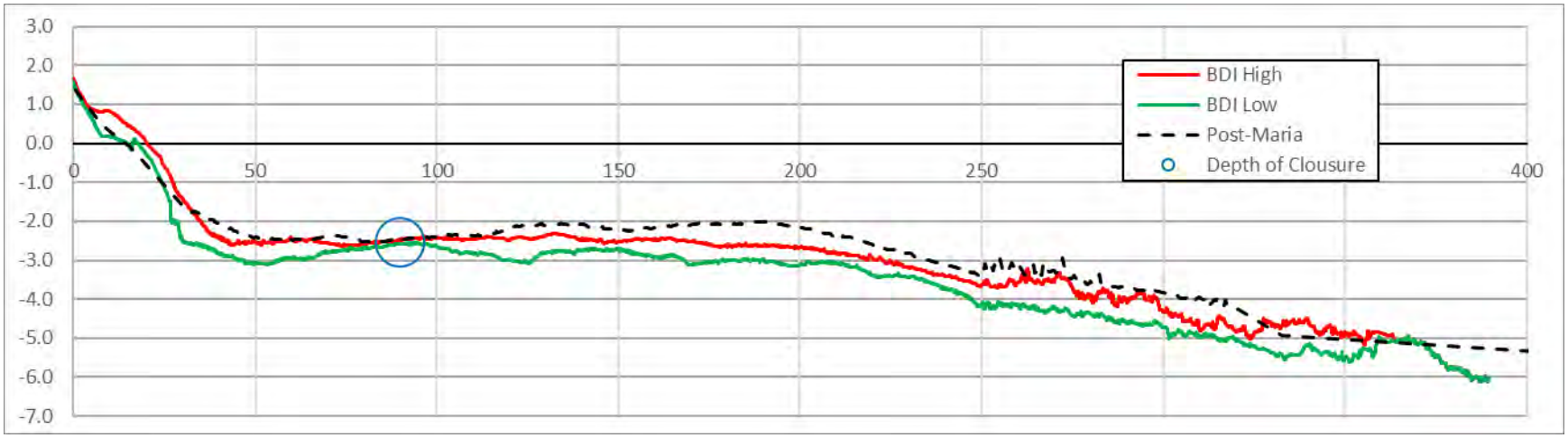

Figure J-91. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 22 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

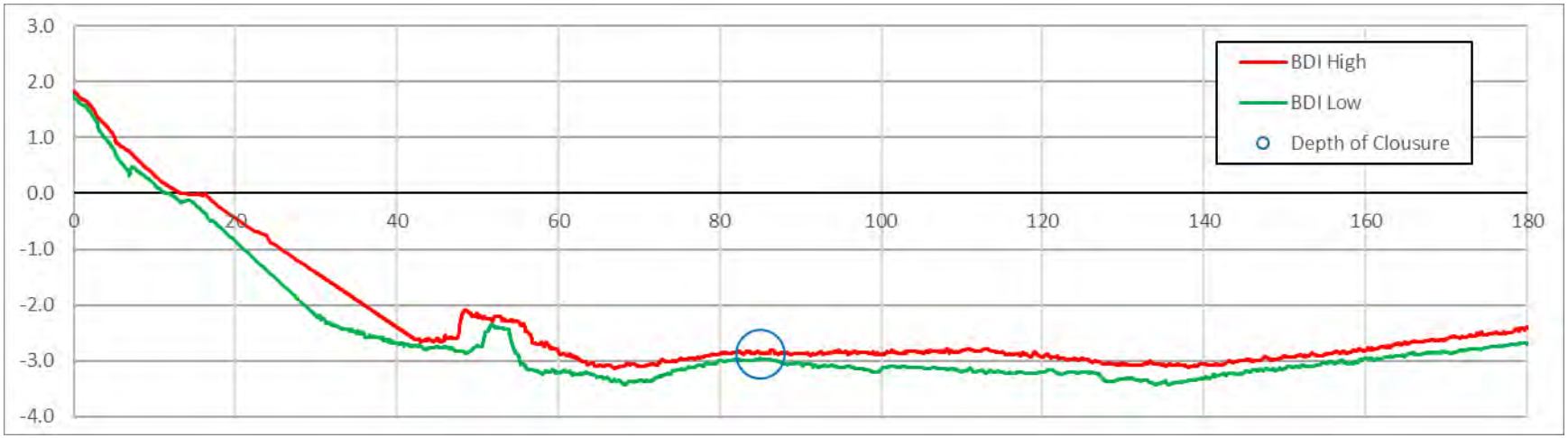

Figure J-92. Envelope of beach profiles and depth of closure at Beach 22 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

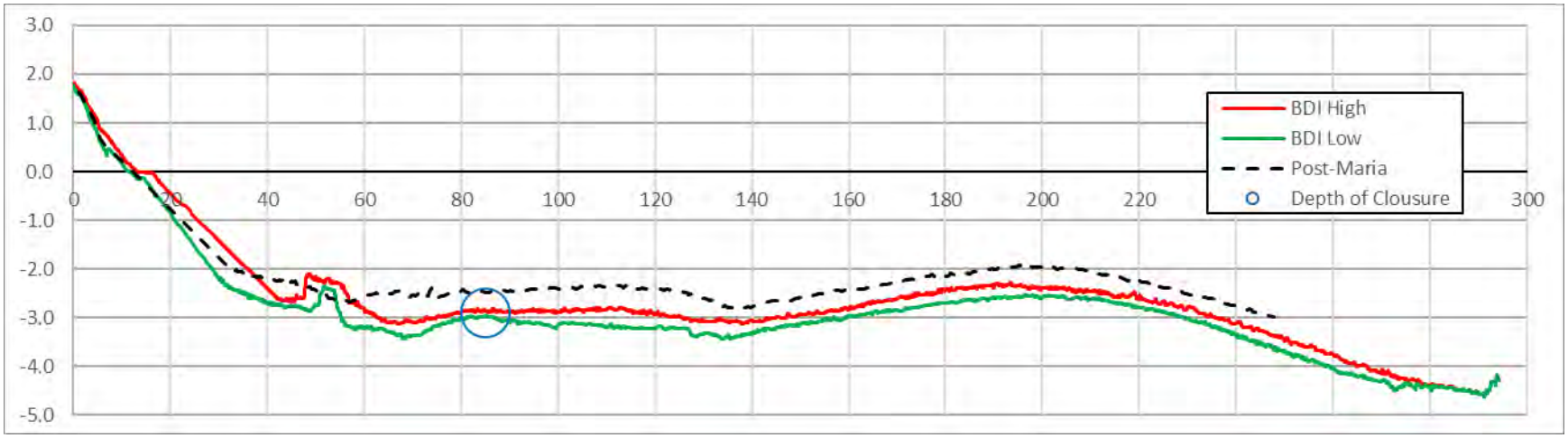

Figure J-93. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 22 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

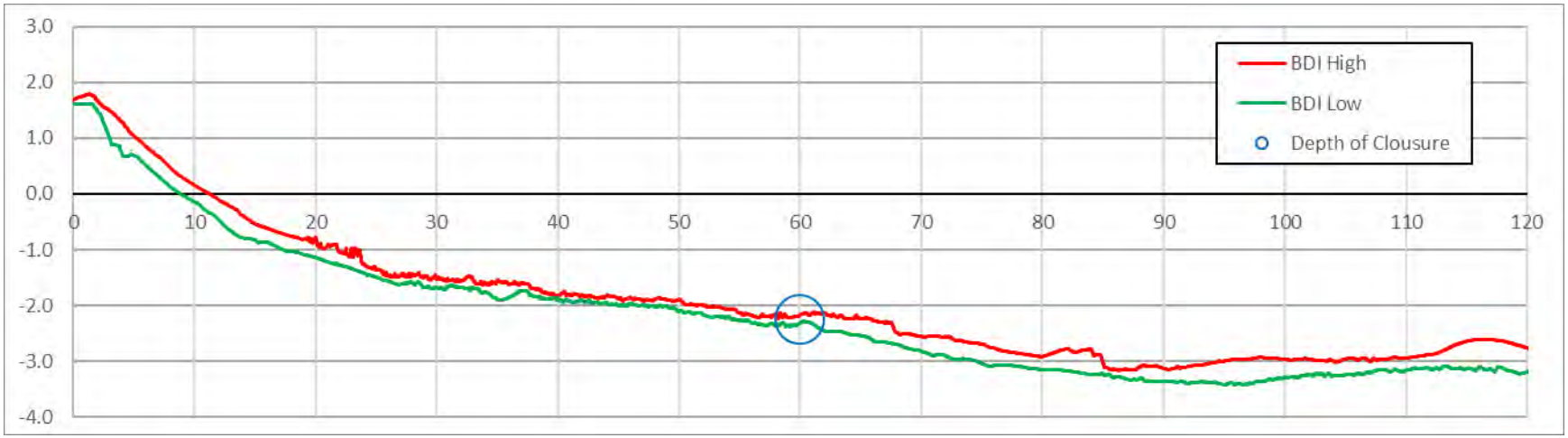

Figure J-94. Envelope of beach profiles and depth of closure at Beach 22 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

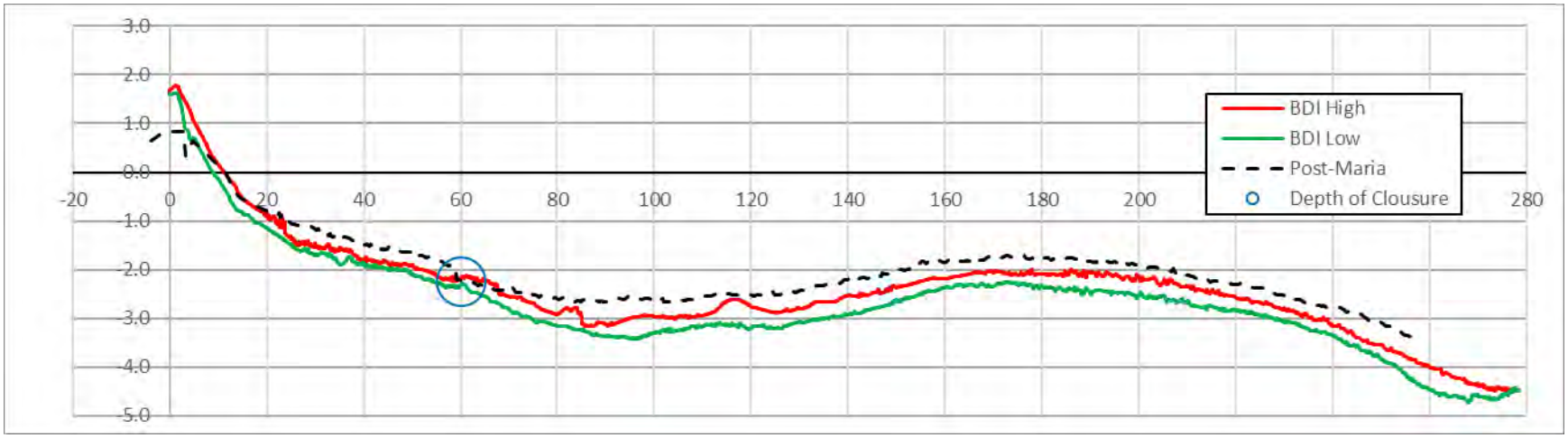

Figure J-95. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 22 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

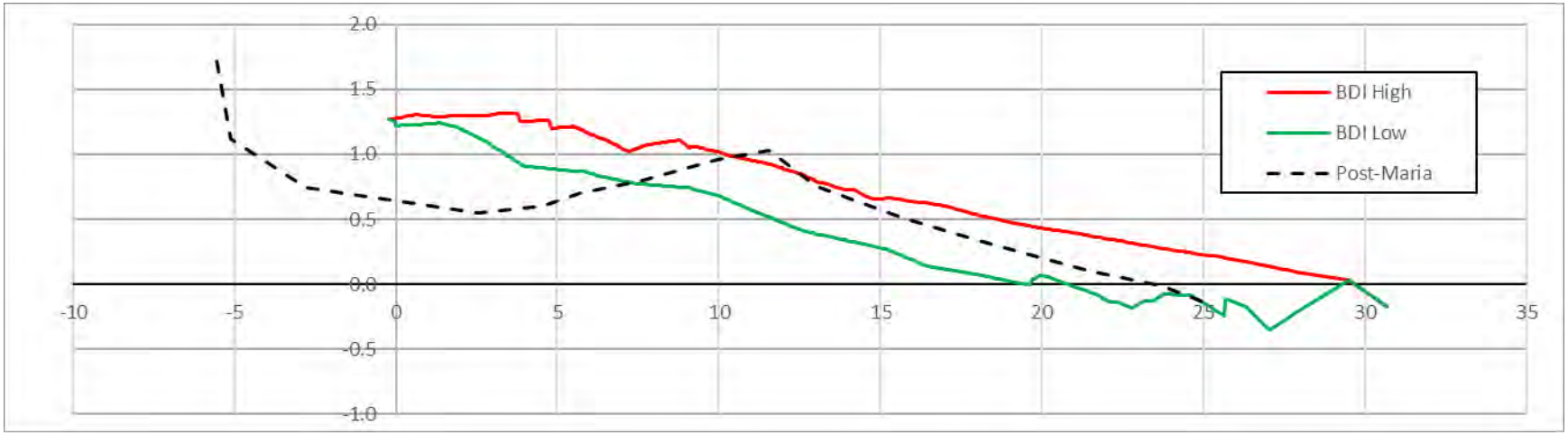

Figure J-96. Envelope of beach profiles and post-Maria profile at Beach 22 transect 6, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

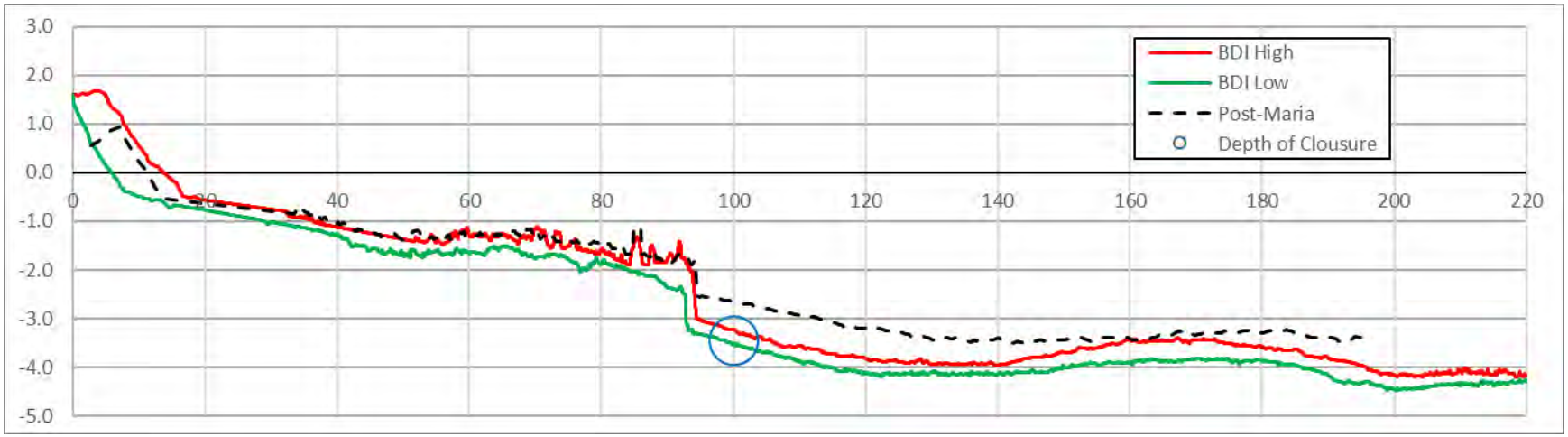

Figure J-97. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 22 transect 7, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

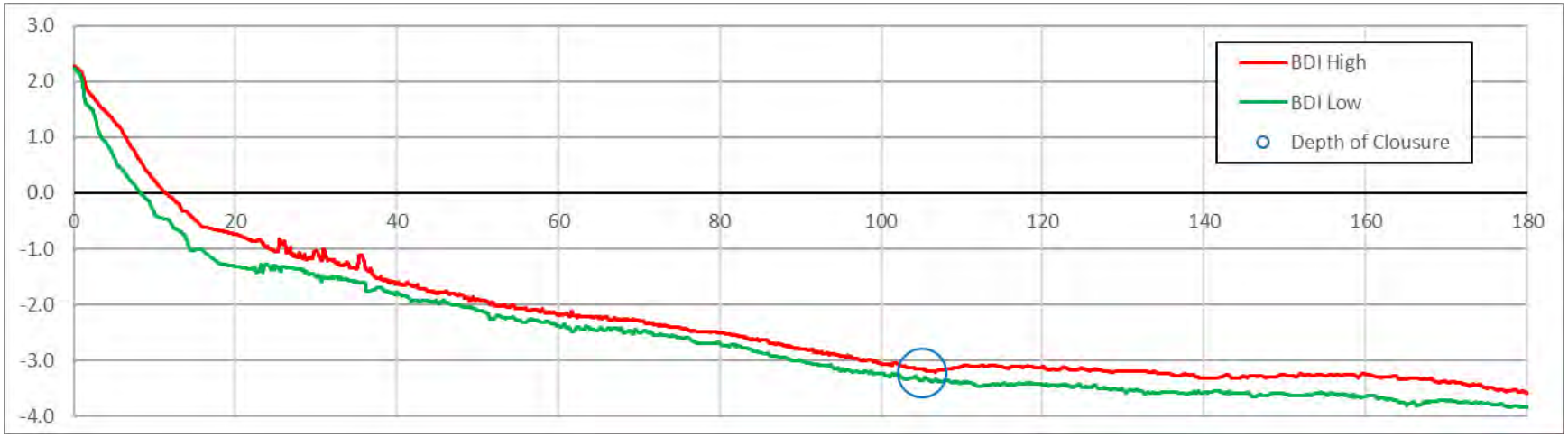

Figure J-98. Envelope of beach profiles and depth of closure at Beach 22 transect 8, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

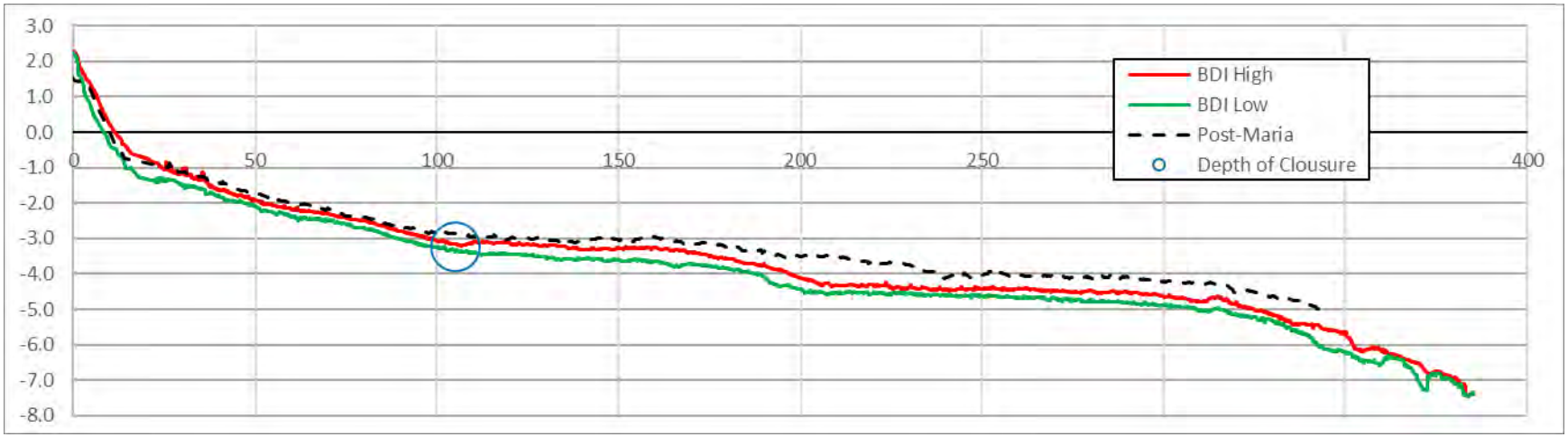

Figure J-99. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 22 transect 8, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

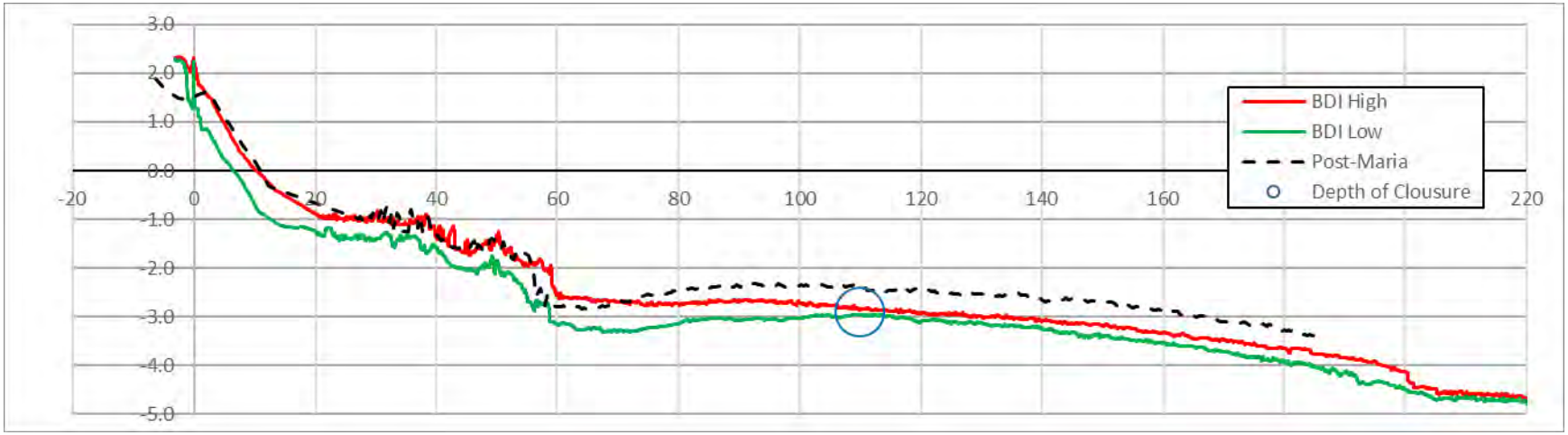

Figure J-100. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 22 transect 9, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

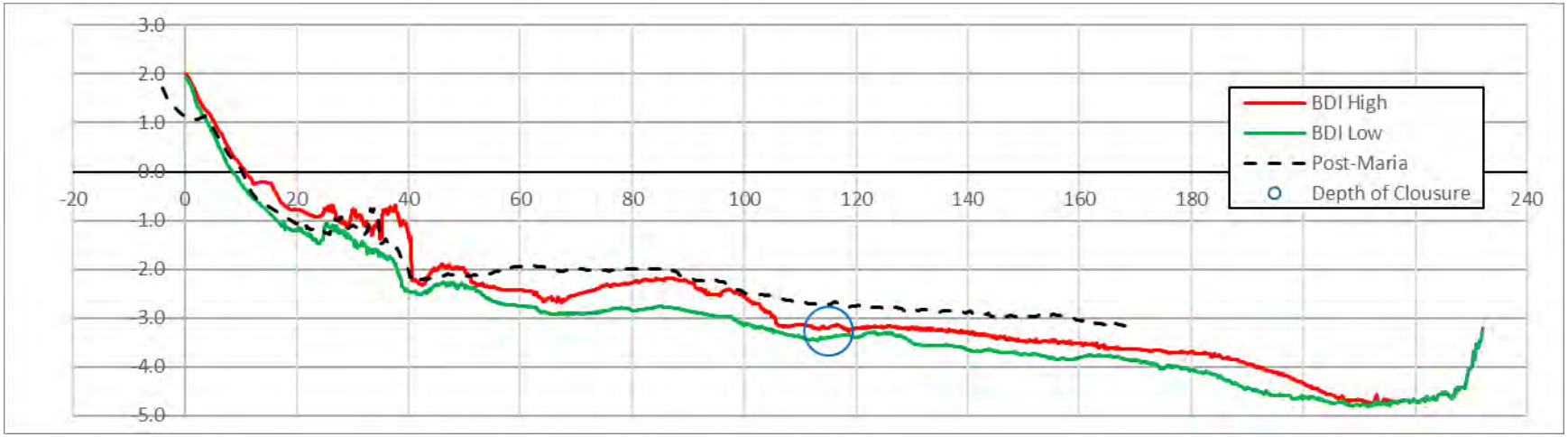

Figure J-101. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 22 transect 10, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Table J-13. Locations of depth of closure and landward limit of beach change, and width of area of beach change during the BDI and Post-Maria for Beach 22.

Transect	Depth of Closure			Landward Limit of Beach Change						Width	
				BDI			Post-Maria				
	Easting	Northing	Depth	Easting	Northing	Elevation	Easting	Northing	Elevation	BDI	Post-Maria
22-01	253,501.0	2,008,082.4	-2.04	253,541.6	2,008,009.2	1.36	253,541.6	2,008,009.2	1.36	83.7	83.7
22-02	253,462.6	2,008,057.6	-2.80	253,473.1	2,007,975.8	1.53	253,473.4	2,007,973.3	0.93	82.5	85.0
22-03	253,414.8	2,008,043.8	-2.53	253,394.4	2,007,959.8	1.00	253,393.3	2,007,955.3	1.58	86.4	91.1
22-04	253,363.0	2,008,047.4	-2.89	253,319.6	2,007,979.1	1.02	253,319.3	2,007,978.7	1.30	80.9	81.4
22-05	253,312.0	2,008,058.9	-2.24	253,268.2	2,008,019.8	1.79	253,264.4	2,008,016.4	0.63	58.7	63.8
22-06				253,218.8	2,008,132.1	1.27	253,214.7	2,008,127.1	1.12		
22-07	253,091.6	2,008,209.9	-3.46	253,093.7	2,008,109.9	1.60	253,093.7	2,008,109.9	0.55	100.0	100.0
22-08	253,069.3	2,008,216.3	-3.23	253,043.2	2,008,116.7	1.52	253,041.8	2,008,111.6	2.22	102.9	108.3
22-09	253,050.5	2,008,234.6	-2.90	252,989.8	2,008,141.7	1.48	252,986.9	2,008,137.2	1.89	111.0	116.3
22-10	253,038.7	2,008,260.9	-3.28	252,946.8	2,008,200.0	0.95	252,939.5	2,008,195.2	1.72	110.3	119.0

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
Depth of closure and elevations of landward limit of beach change relative to PRVD02
Width (of the area of beach change) = horizontal distance along the transect between the depth of closure and landward limit of beach change

Table J-14. Locations of maximum beach elevation change, ranges, and high and low elevations of envelope for Beach 22.

Transect	Easting	Northing	Range	High	Low
22-01	253,537.8	2,008,016.1	0.72	0.52	-0.20
22-02	253,472.1	2,007,983.1	0.68	0.94	0.25
22-03	253,399.9	2,007,982.4	1.14	-0.86	-2.00
22-04	253,334.2	2,008,002.0	0.79	-1.54	-2.33
22-05	253,270.3	2,008,021.6	0.59	1.27	0.68
22-06	253,232.6	2,008,148.5	0.50	0.32	-0.18
22-07	253,093.5	2,008,117.2	1.48	1.18	-0.30
22-08	253,044.1	2,008,120.2	0.73	1.20	0.47
22-09	252,990.3	2,008,142.4	0.97	2.24	1.27
22-10	252,955.7	2,008,205.9	0.64	-0.24	-0.88

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
High and low elevations relative to PRVD02

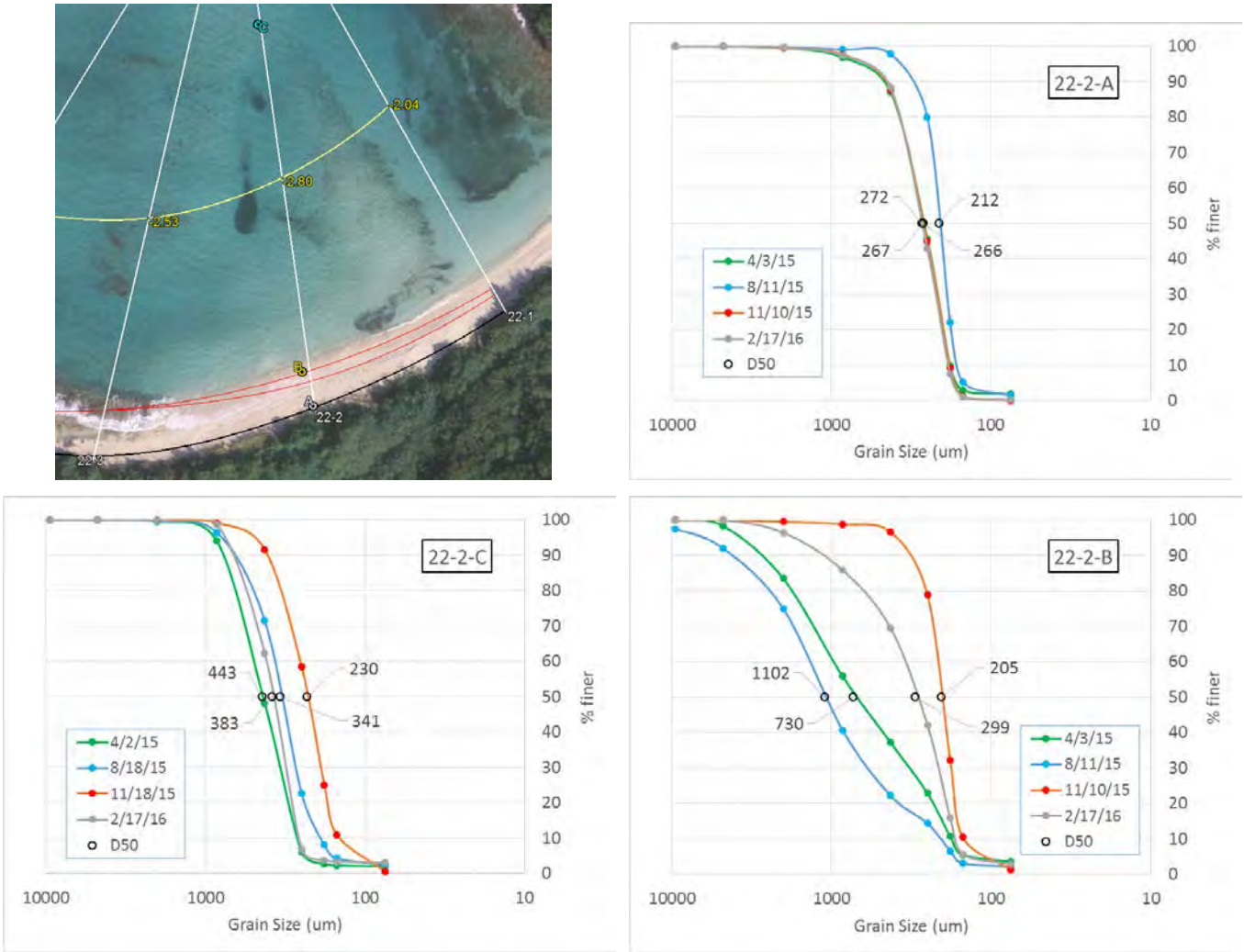

Figure J-102. Clockwise from top: approximate locations of sediment samples at Beach 22 (east), BDI landward limit of beach change, maximum landward and seaward shoreline positions, depth of closure; and distribution of grain size at backshore (A), shoreline (B) and nearshore (C) locations.

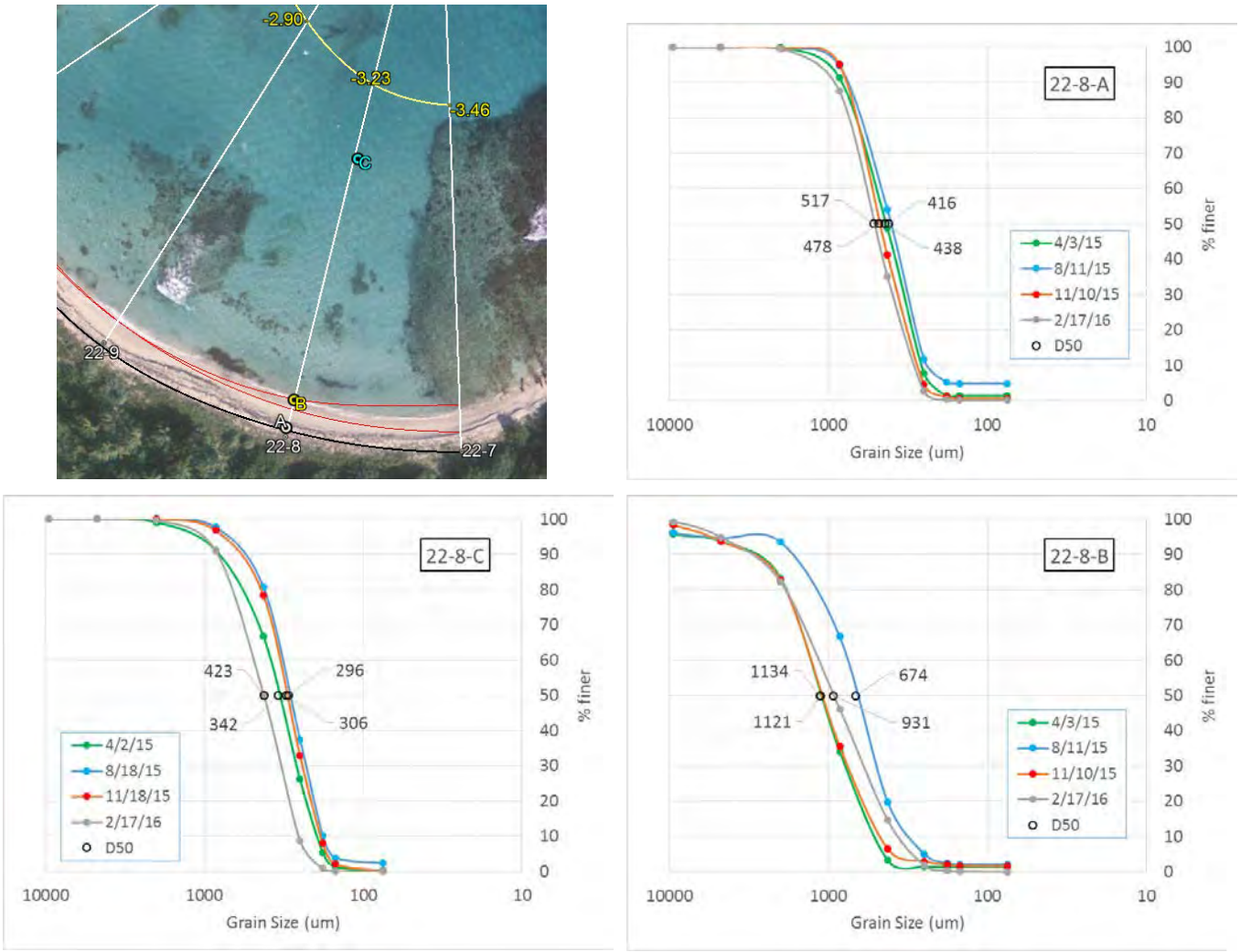

Figure J-103. Clockwise from top: approximate locations of sediment samples at Beach 22 (west), BDI landward limit of beach change, maximum landward and seaward shoreline positions, depth of closure; and distribution of grain size at backshore (A), shoreline (B) and nearshore (C) locations.

North EMA and SIA UXO 7
Beach 24

Figure J-104. Beach 24 transects, bathymetry and coastal features.

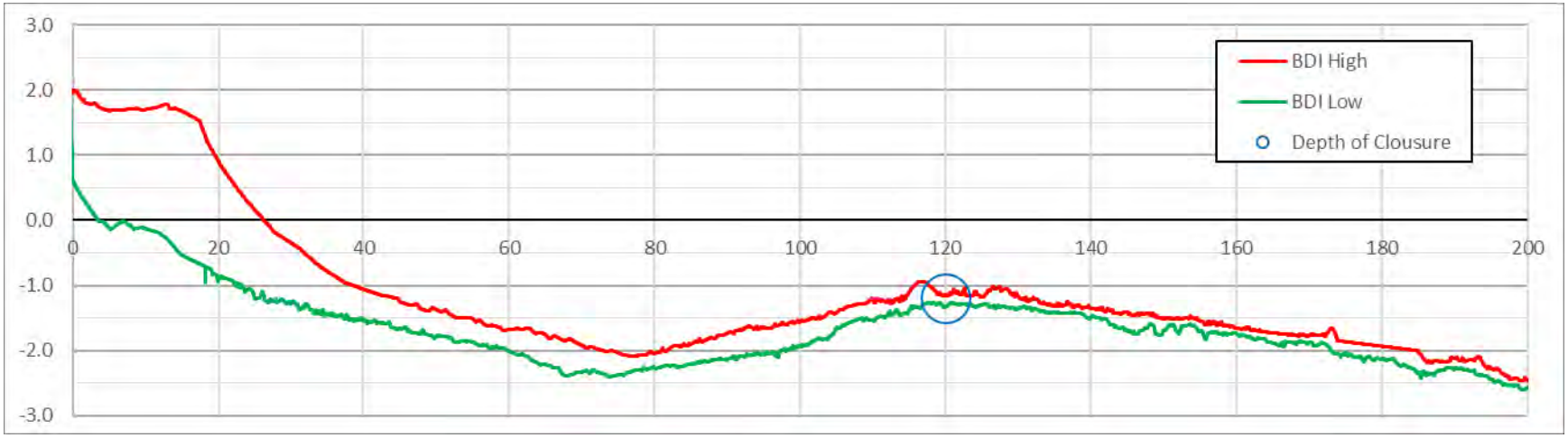

Figure J-105. Envelope of beach profiles and depth of closure at Beach 24 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

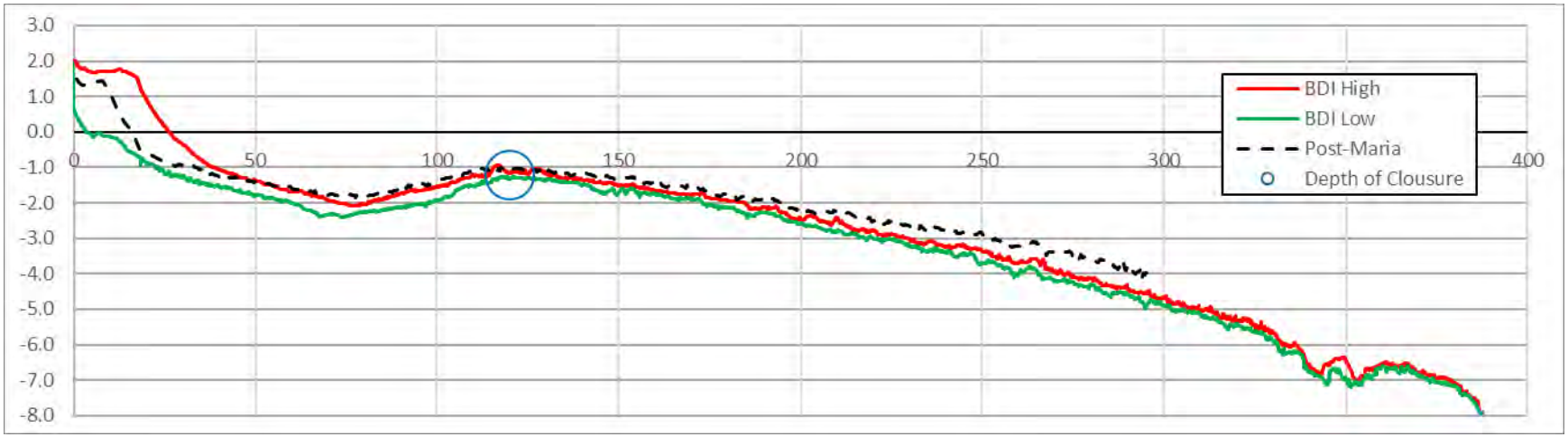

Figure J-106. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 24 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

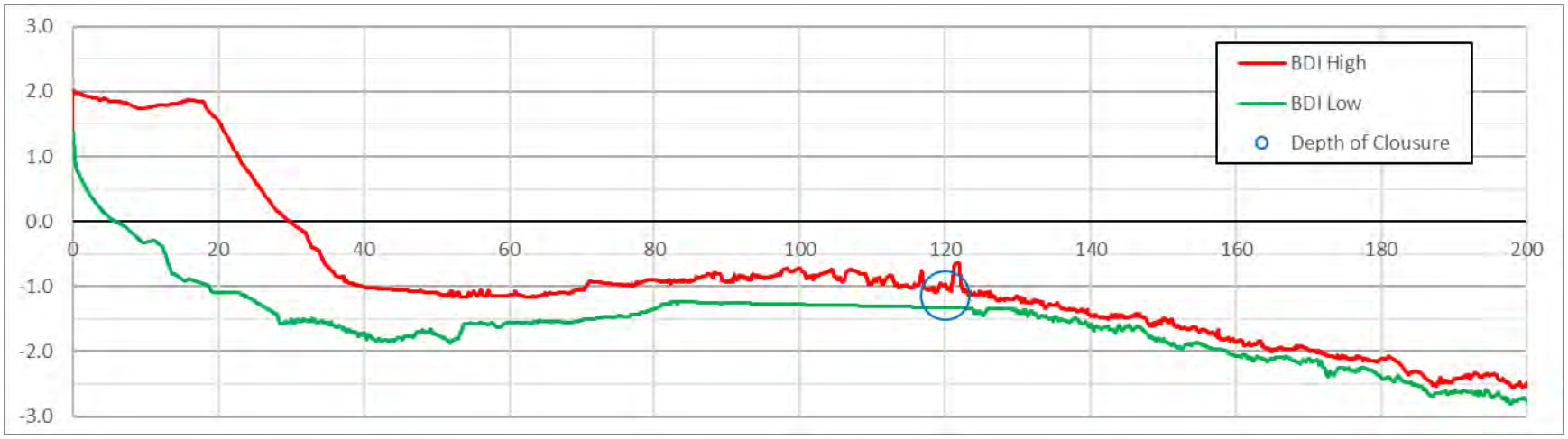

Figure J-107. Envelope of beach profiles and depth of closure at Beach 24 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

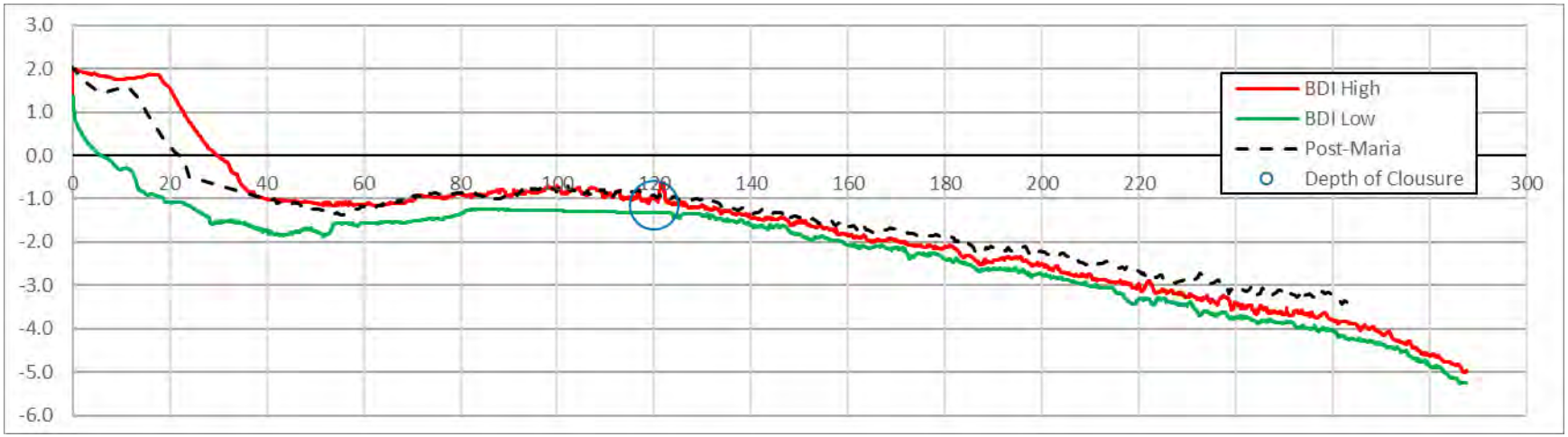

Figure J-108. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 24 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

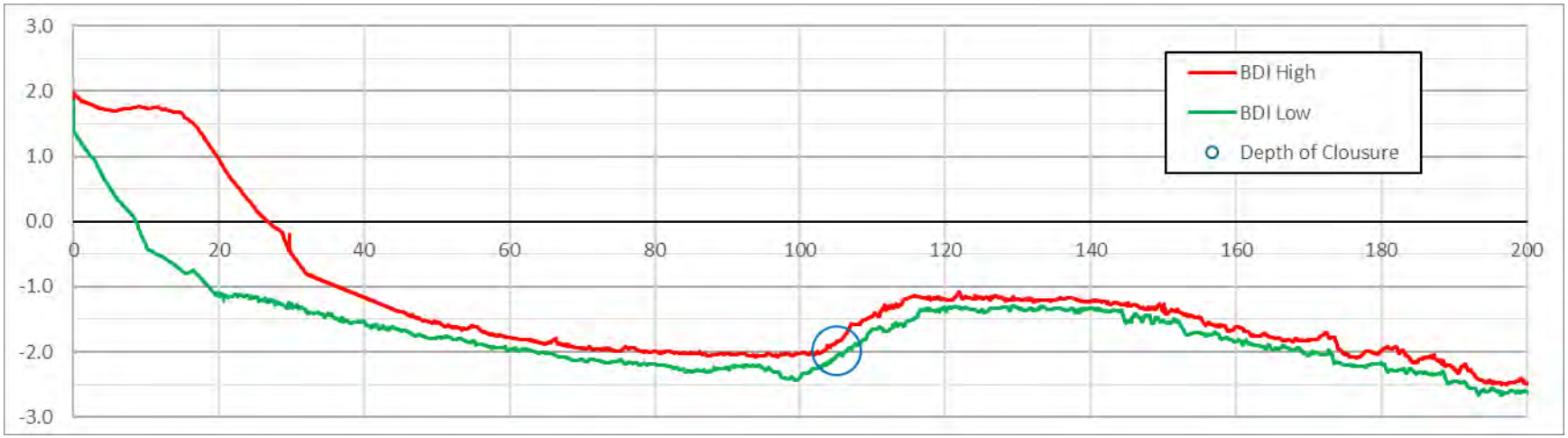

Figure J-109. Envelope of beach profiles and depth of closure at Beach 24 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

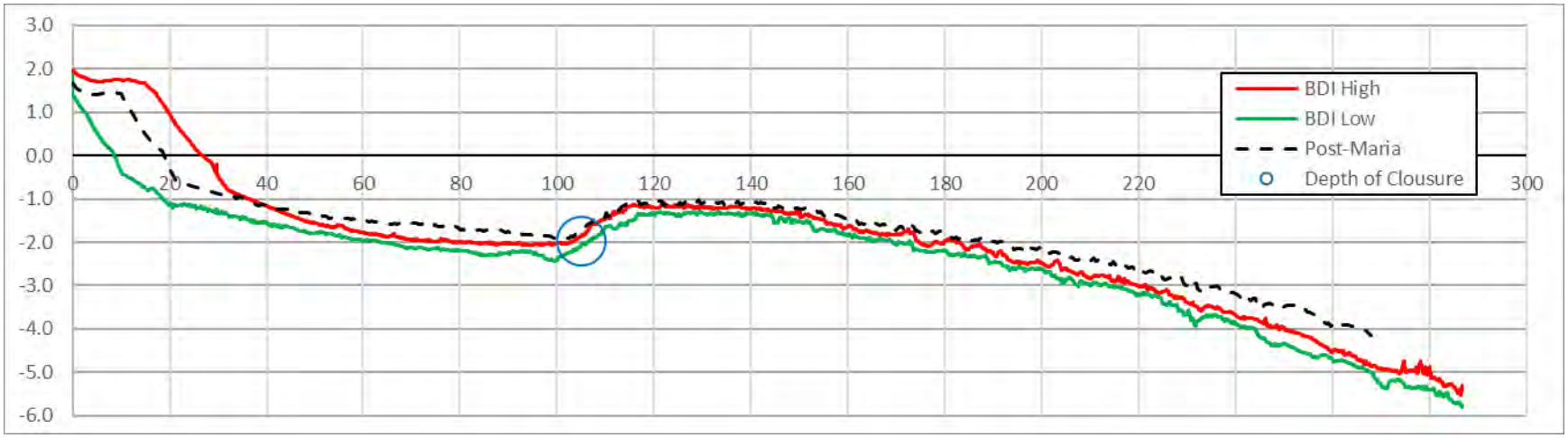

Figure J-110. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 24 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

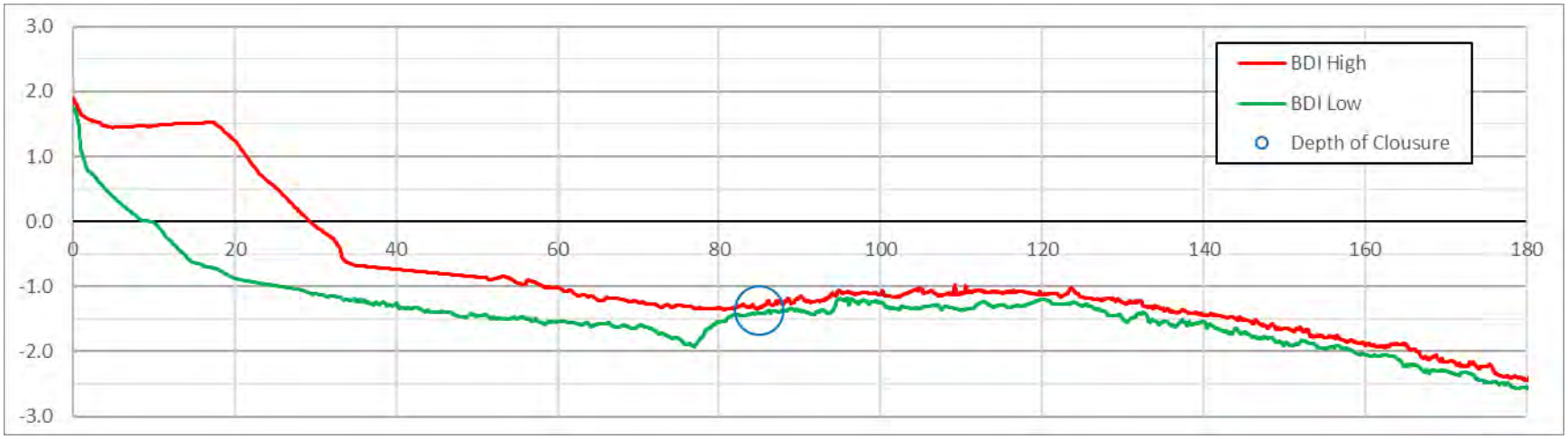

Figure J-111. Envelope of beach profiles and depth of closure at Beach 24 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

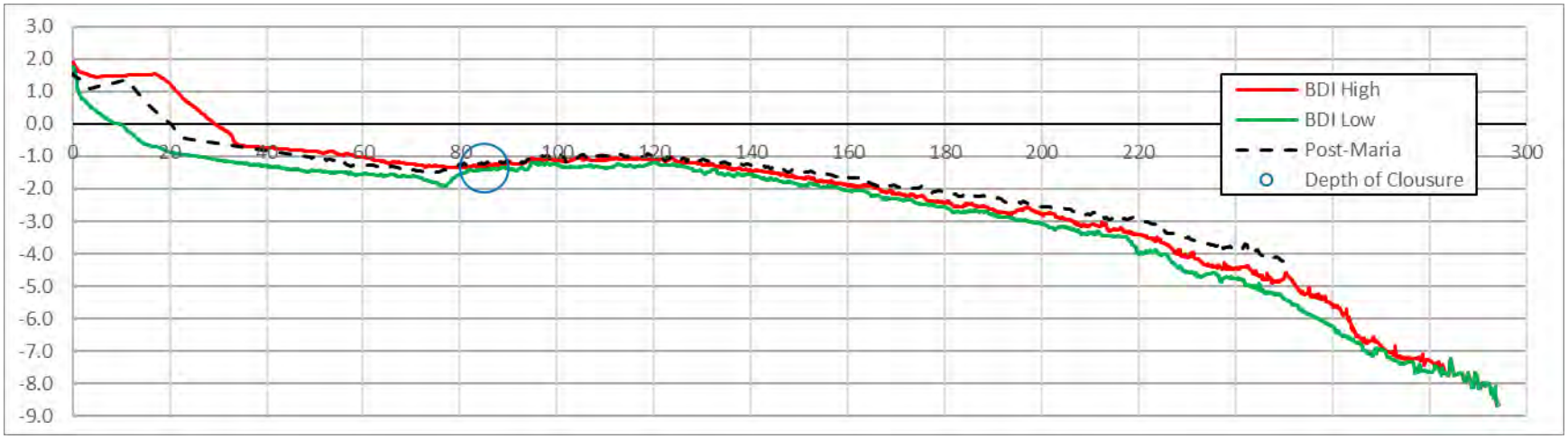

Figure J-112. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 24 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

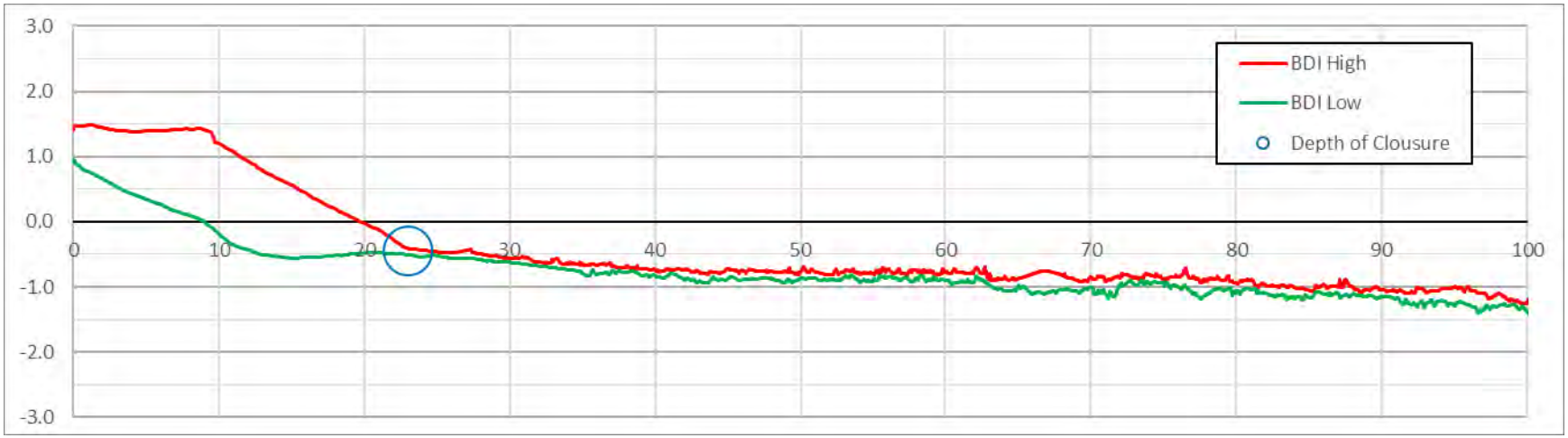

Figure J-113. Envelope of beach profiles and depth of closure at Beach 24 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

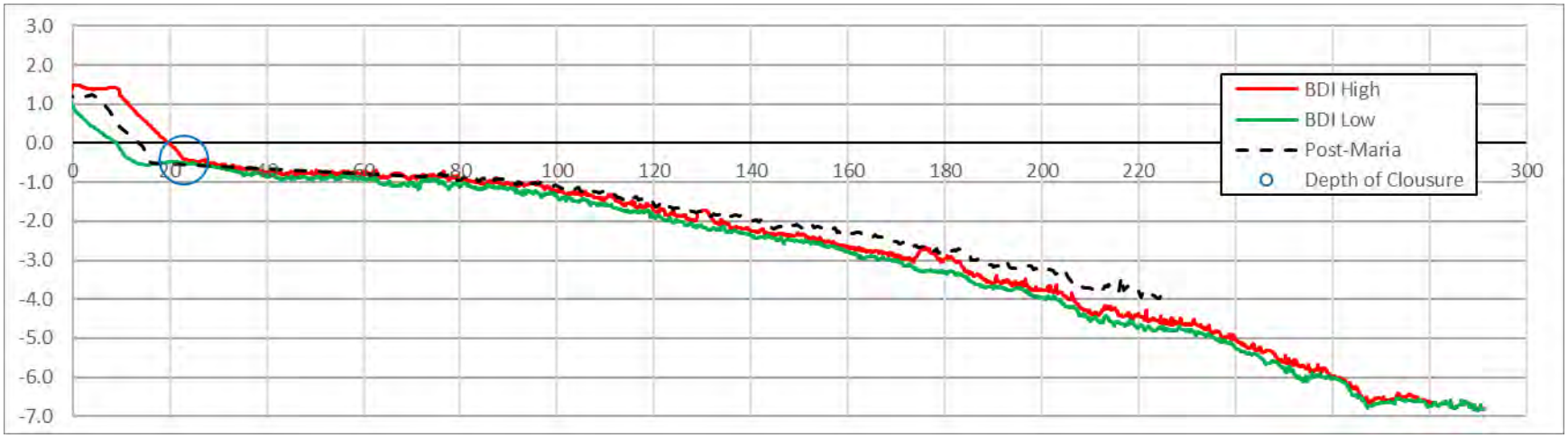

Figure J-114. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 24 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

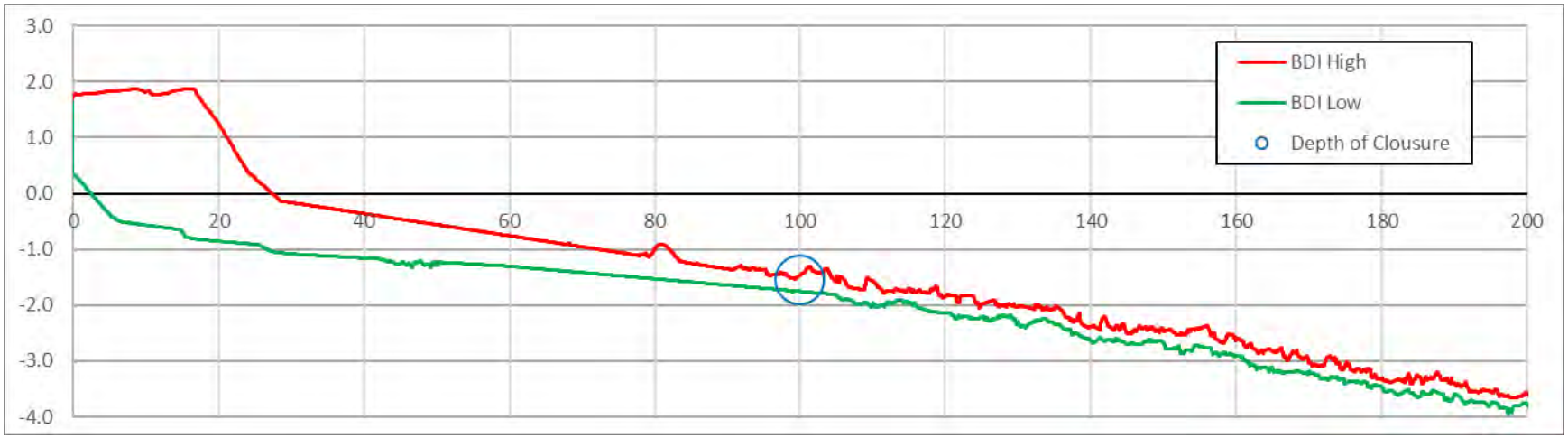

Figure J-115. Envelope of beach profiles and depth of closure at Beach 24 transect 6, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

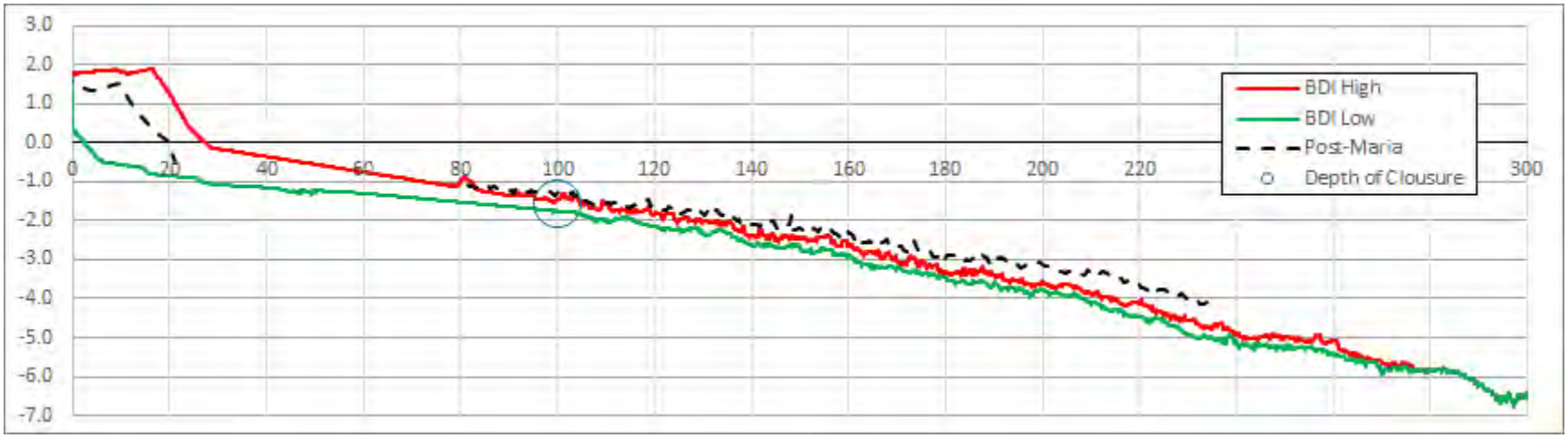

Figure J-116. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 24 transect 6, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

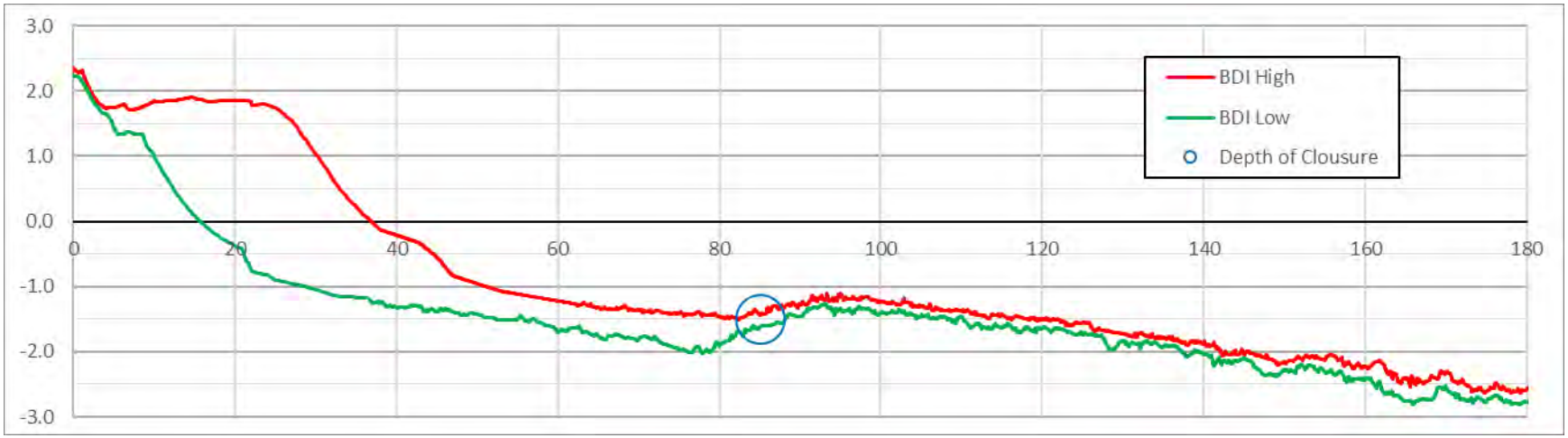

Figure JError! No text of specified style in document.-117. Envelope of beach profiles and depth of closure at Beach 24 transect 7, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

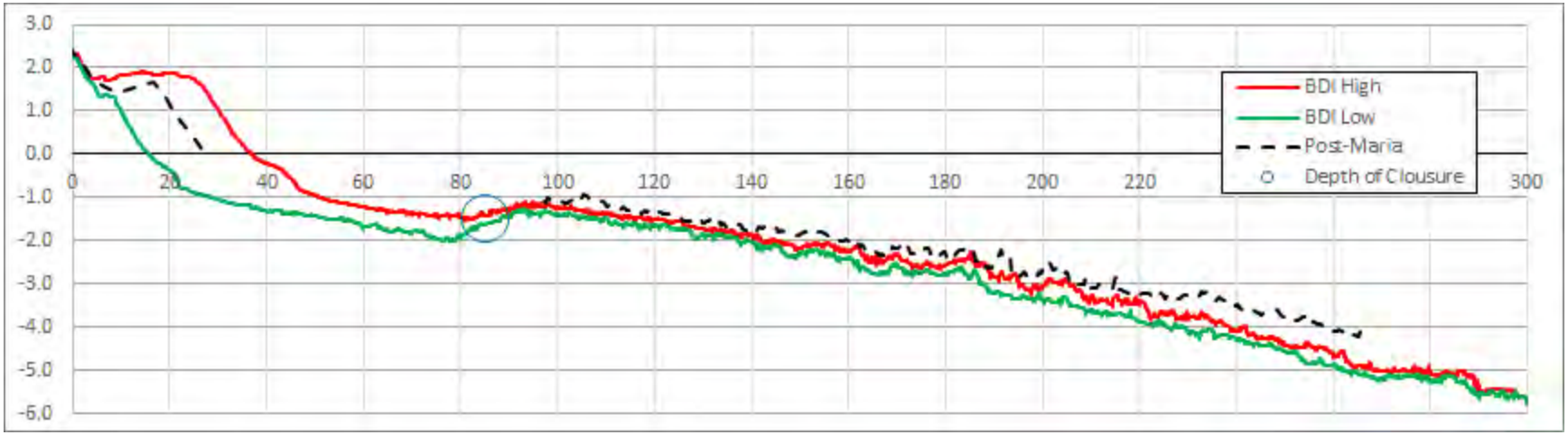

Figure J-118. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 24 transect 7, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

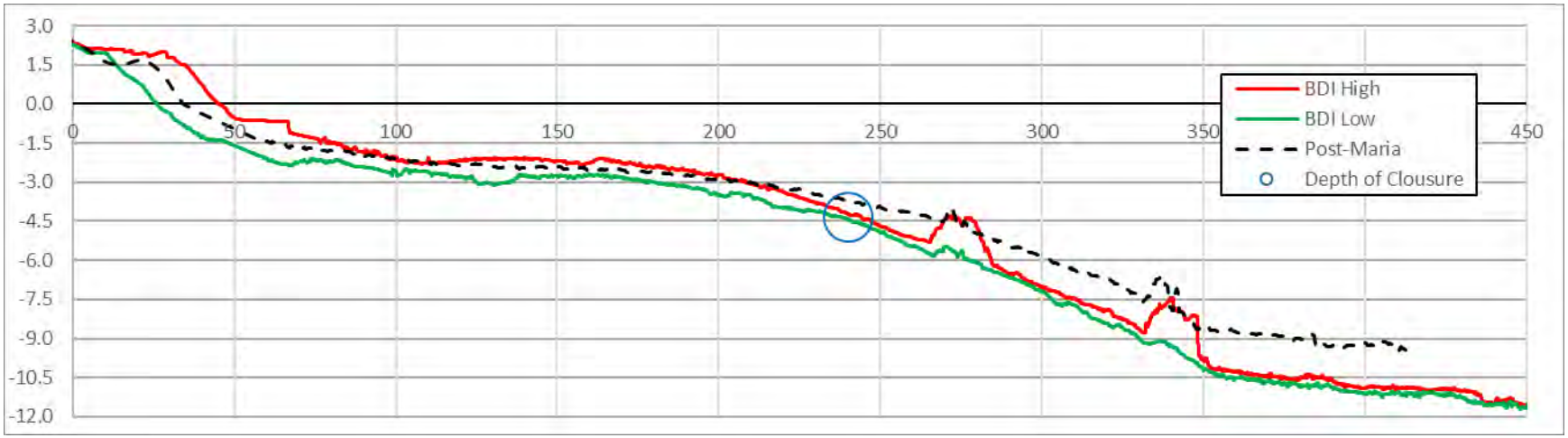

Figure J-119. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 24 transect 8, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

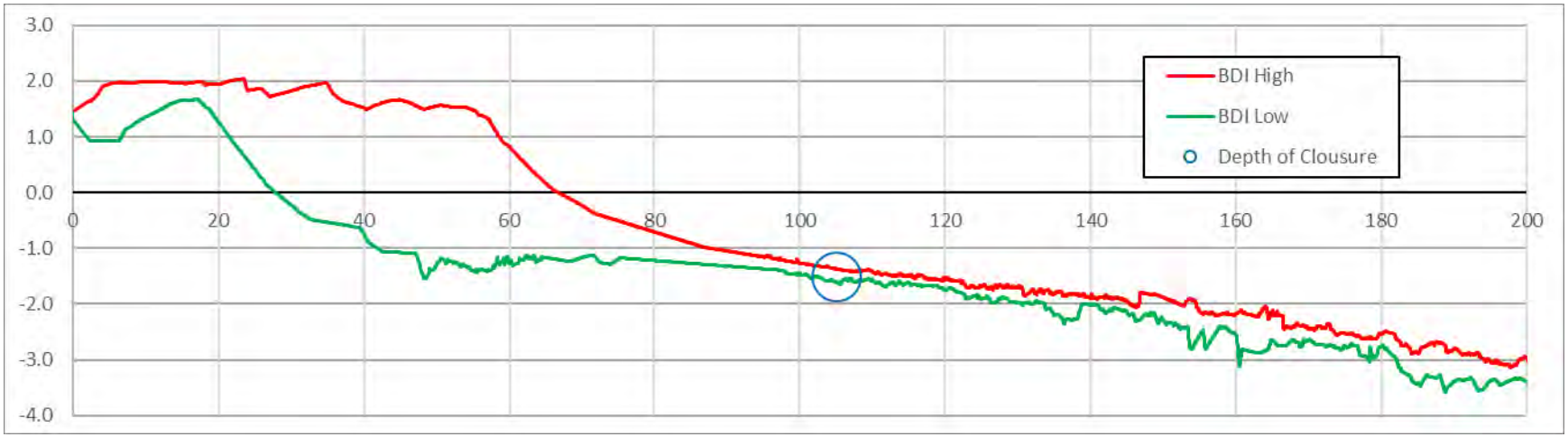

Figure J-120. Envelope of beach profiles and depth of closure at Beach 24 transect 9, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

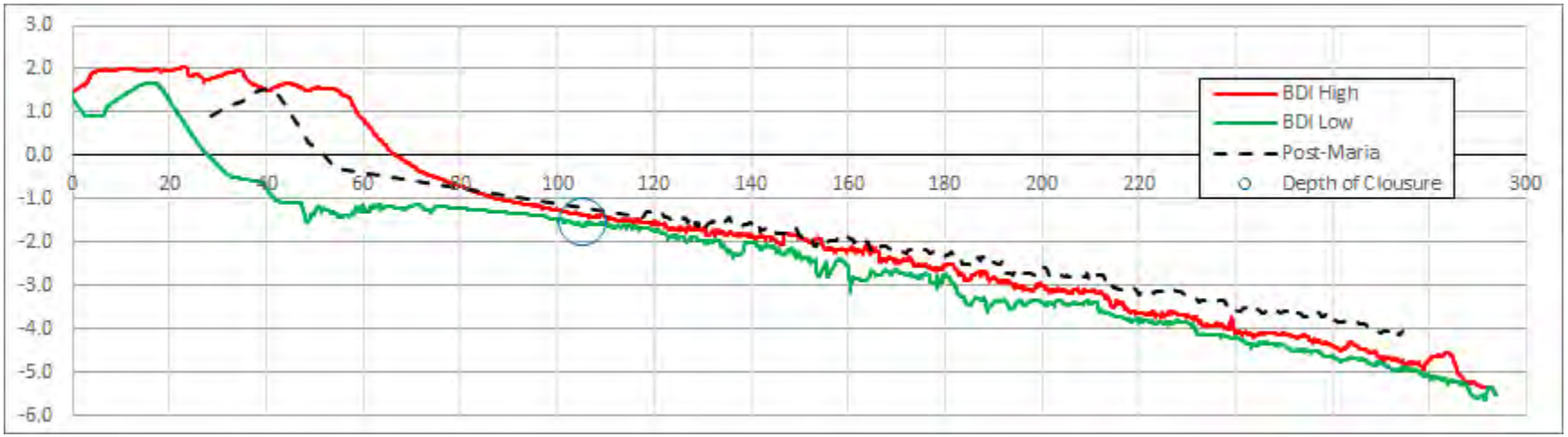

Figure J-121. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 24 transect 9, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

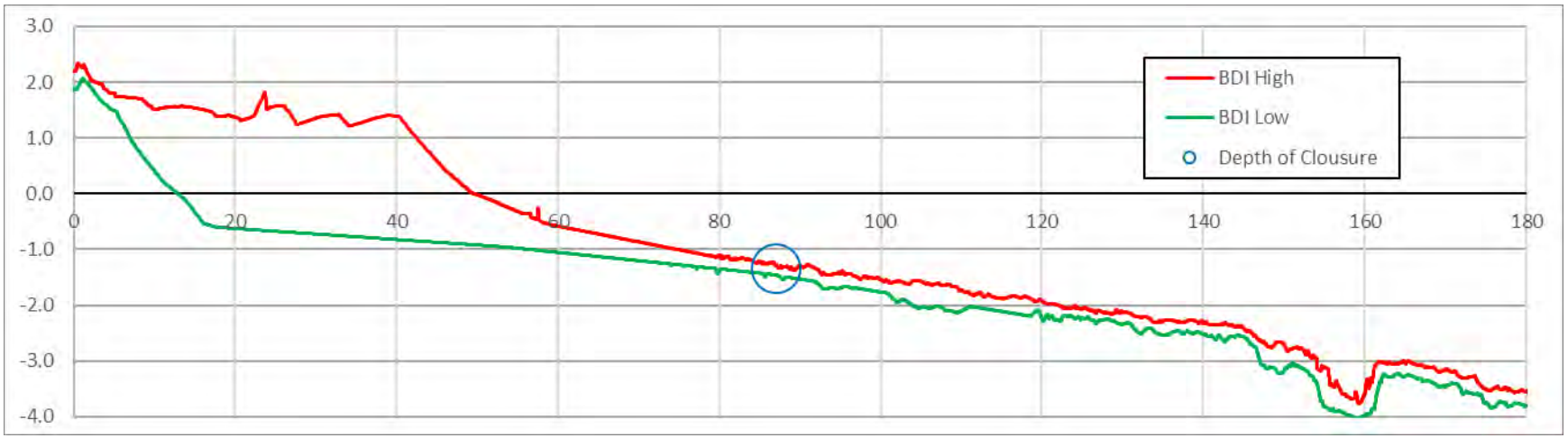

Figure J-122. Envelope of beach profiles and depth of closure at Beach 24 transect 10, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

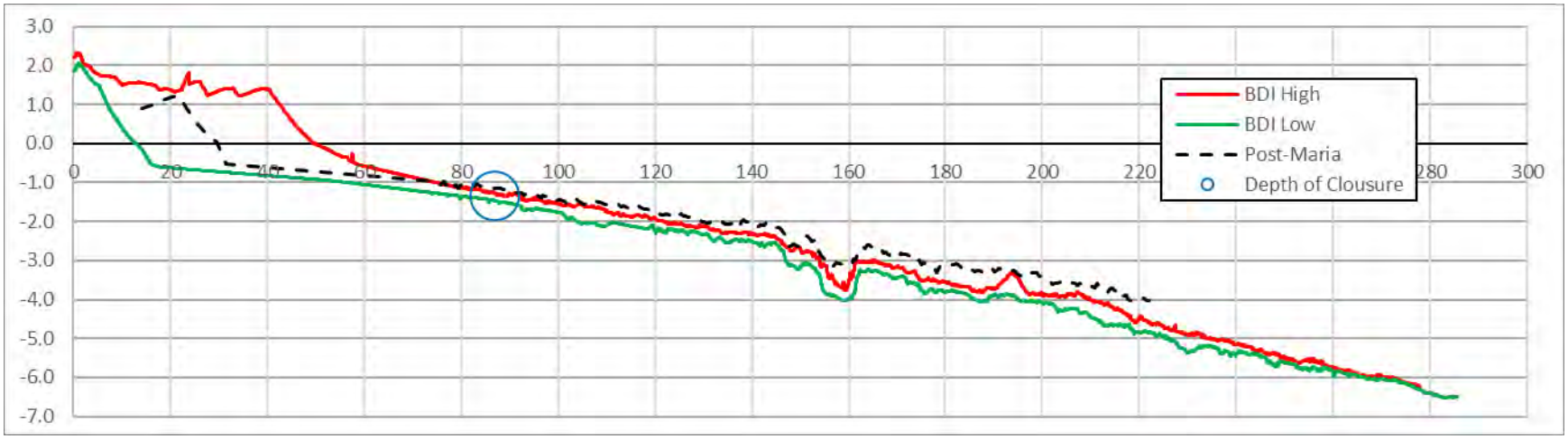

Figure J-123. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 24 transect 10, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Figure J-124. Envelope of beach profiles and depth of closure at Beach 24 transect 11, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

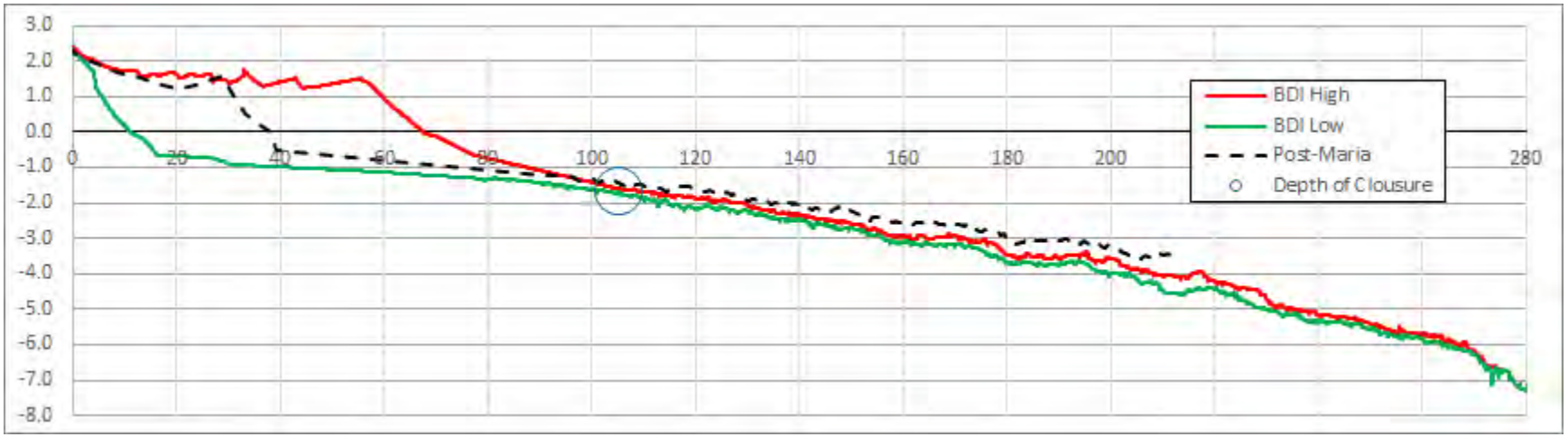

Figure JError! No text of specified style in document.-125. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 24 transect 11, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Table J-15. Locations of depth of closure and landward limit of beach change, and width of area of beach change during the BDI and Post-Maria for Beach 24.

Transect	Depth of Closure			Landward Limit of Beach Change						Width	
				BDI			Post-Maria				
	Easting	Northing	Depth	Easting	Northing	Elevation	Easting	Northing	Elevation	BDI	Post-Maria
24-01	249,063.5	2,009,308.1	-1.21	249,073.0	2,009,188.5	1.88	249,073.2	2,009,185.5	2.10	120.0	123.0
24-02	248,980.6	2,009,307.9	-1.14	248,979.1	2,009,187.9	1.98	248,979.1	2,009,187.9	2.10	120.0	120.0
24-03	248,894.8	2,009,303.3	-1.98	248,882.4	2,009,199.1	1.88	248,882.1	2,009,196.6	2.00	105.0	107.5
24-04	248,805.3	2,009,310.1	-1.37	248,790.0	2,009,226.5	1.79	248,789.6	2,009,224.1	1.80	85.0	87.5
24-05	248,710.6	2,009,288.9	-0.45	248,705.4	2,009,266.5	1.50	248,704.6	2,009,263.3	1.93	23.0	26.4
24-06	248,628.5	2,009,376.1	-1.55	248,610.1	2,009,277.9	1.73	248,609.7	2,009,276.1	1.74	100.0	101.8
24-07	248,526.7	2,009,375.1	-1.50	248,509.1	2,009,296.7	1.74	248,509.1	2,009,296.7	1.74	80.4	80.4
24-08	248,453.0	2,009,551.8	-4.34	248,384.0	2,009,331.7	2.09	248,382.8	2,009,328.0	2.01	230.6	234.6
24-09	248,332.4	2,009,447.4	-1.52	248,300.8	2,009,364.9	1.90	248,300.8	2,009,364.9	1.90	88.3	88.3
24-10	248,273.8	2,009,494.6	-1.34	248,244.0	2,009,418.6	1.70	248,244.0	2,009,418.6	1.70	81.6	81.6
24-11	248,206.1	2,009,537.6	-1.67	248,172.6	2,009,444.0	1.68	248,172.6	2,009,444.0	1.68	99.4	99.4

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
Depth of closure and elevations of landward limit of beach change relative to PRVD02
Width (of the area of beach change) = horizontal distance along the transect between the depth of closure and landward limit of beach change

Table J-16. Locations of maximum beach elevation change, ranges, and high and low elevations of envelope for Beach 24.

Transect	Easting	Northing	Range	High	Low
24-01	249,071.5	2,009,206.7	2.21	1.27	-0.94
24-02	248,979.4	2,009,205.8	2.80	1.85	-0.96
24-03	248,884.2	2,009,214.0	2.42	1.66	-0.76
24-04	248,793.1	2,009,243.7	2.23	1.52	-0.71
24-05	248,707.5	2,009,275.8	1.47	1.39	-0.08
24-06	248,613.1	2,009,294.2	2.69	1.88	-0.81
24-07	248,513.6	2,009,316.6	2.64	1.74	-0.90
24-08	248,391.7	2,009,356.1	2.37	1.49	-0.88
24-09	248,312.2	2,009,394.6	3.05	1.50	-1.55
24-10	248,250.7	2,009,435.7	2.48	1.82	-0.66
24-11	248,181.8	2,009,469.7	2.70	1.76	-0.94

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
High and low elevations relative to PRVD02

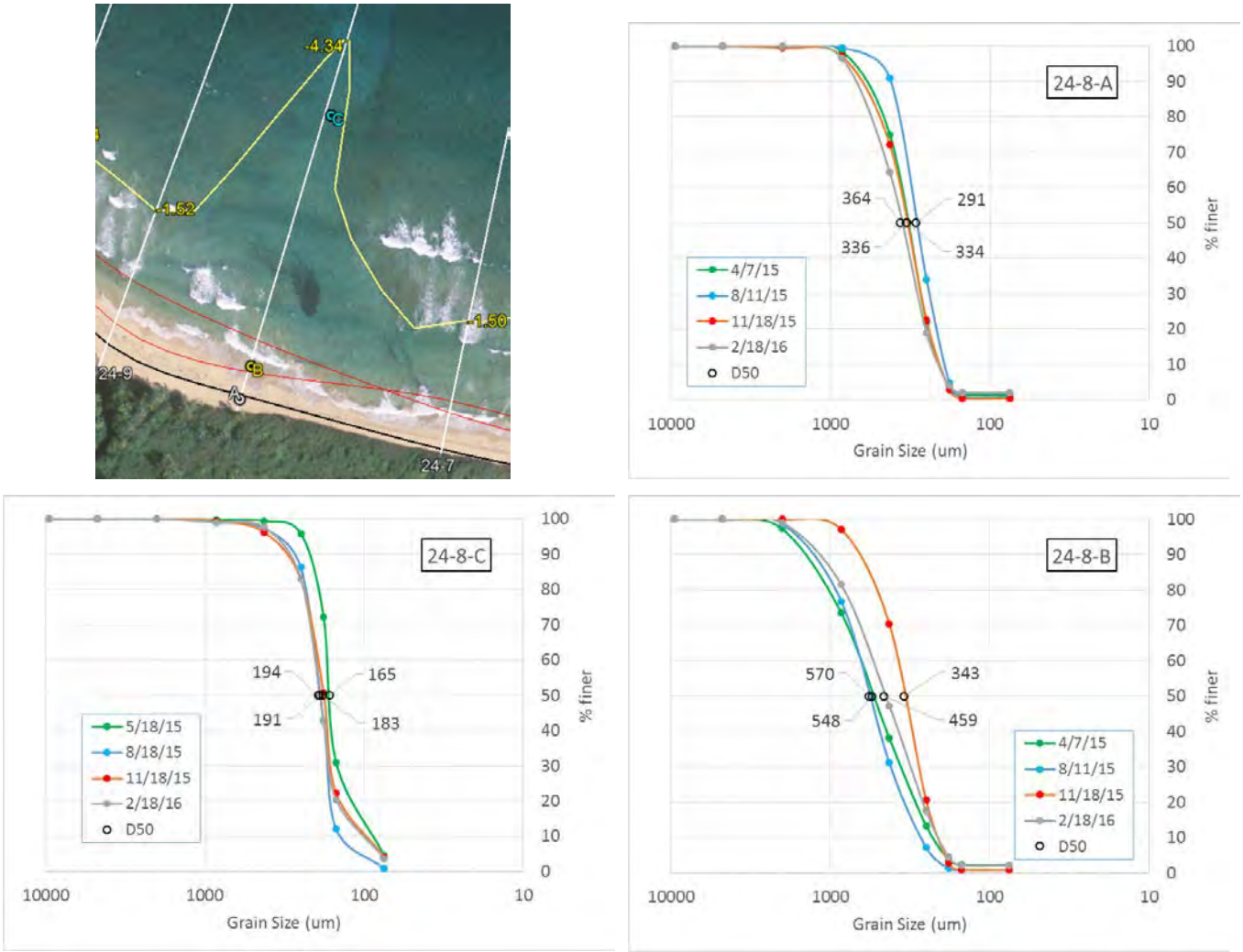

Figure J-126. Clockwise from top: approximate locations of sediment samples at Beach 24, BDI landward limit of beach change, maximum landward and seaward shoreline positions, depth of closure; and distribution of grain size at backshore (A), shoreline (B) and nearshore (C) locations.

South SIA UXO 8
Beach 1

Figure J-127. Beach 1 transects, bathymetry and coastal features.

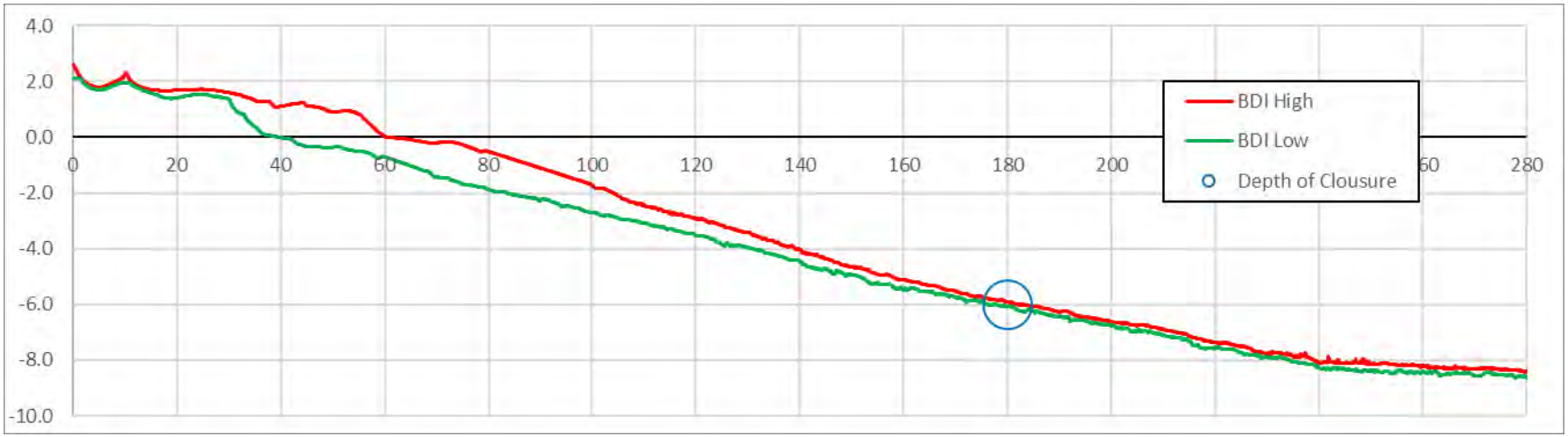

Figure J-128. Envelope of beach profiles and depth of closure at Beach 1 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

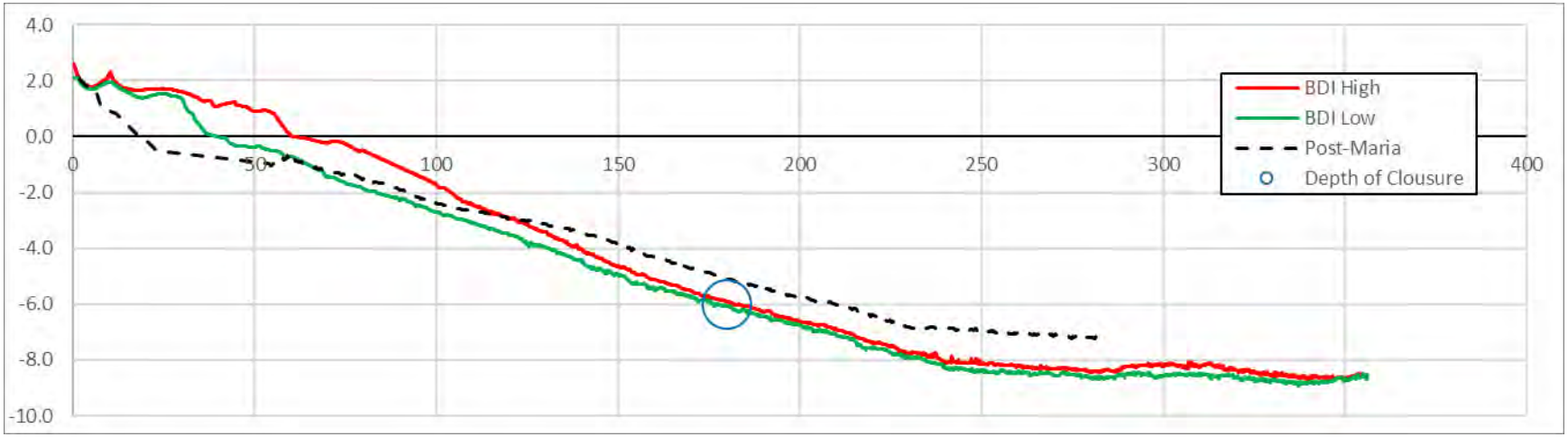

Figure J-129. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 1 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

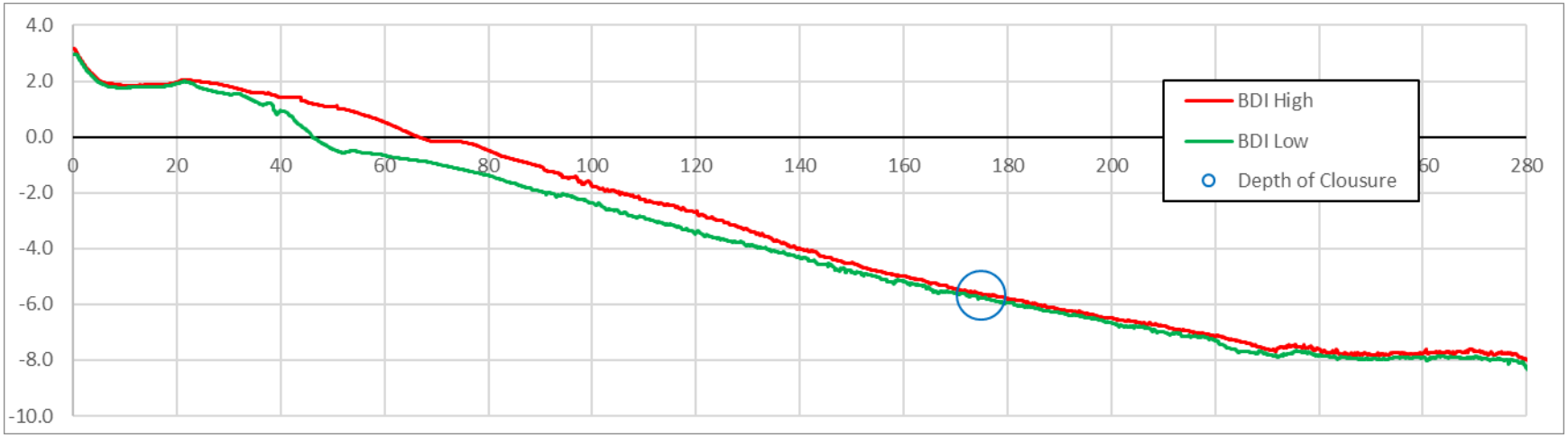

Figure J-130. Envelope of beach profiles and depth of closure at Beach 1 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

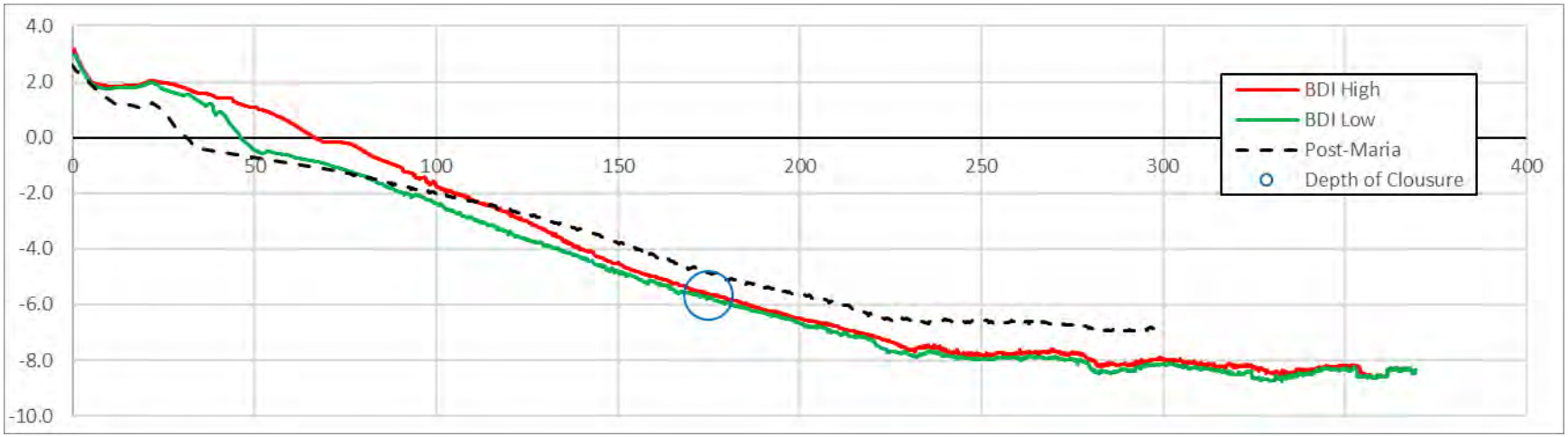

Figure J-131. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 1 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

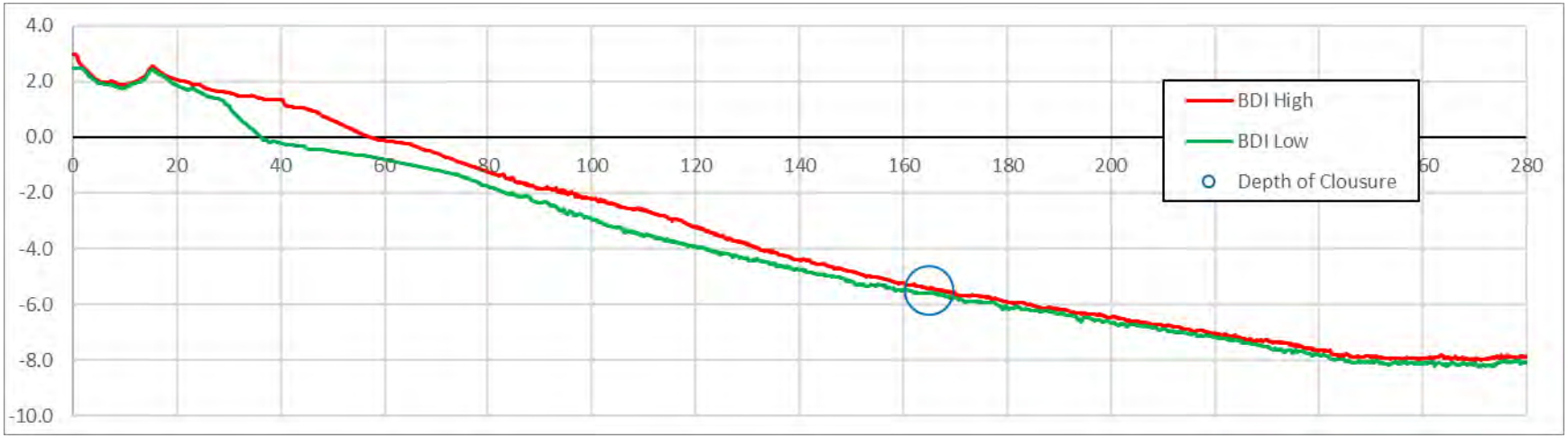

Figure J-132. Envelope of beach profiles and depth of closure at Beach 1 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

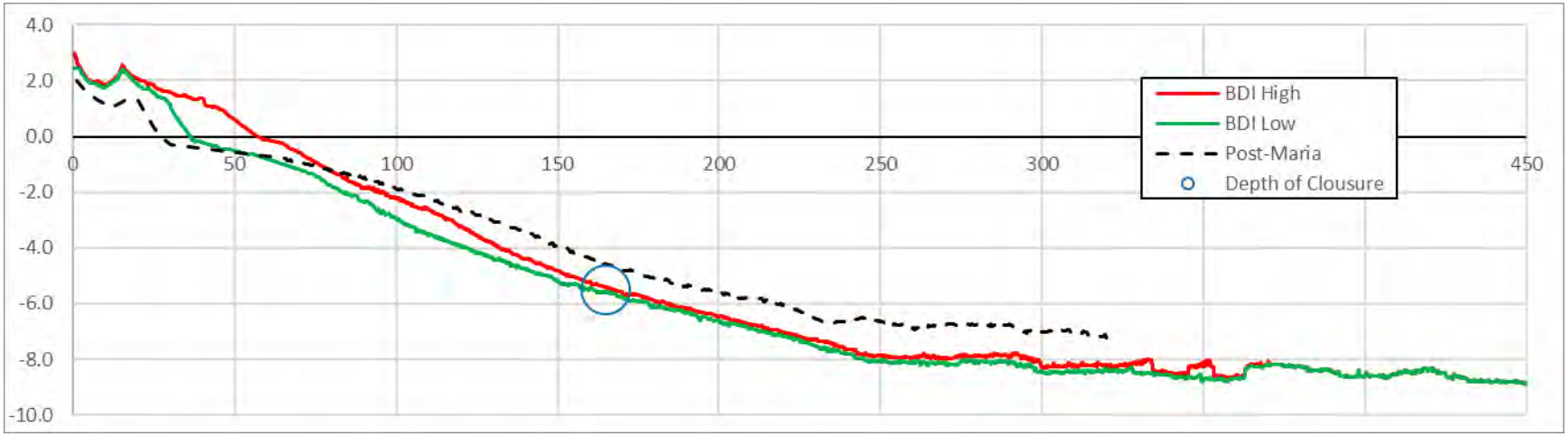

Figure J-133. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 1 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

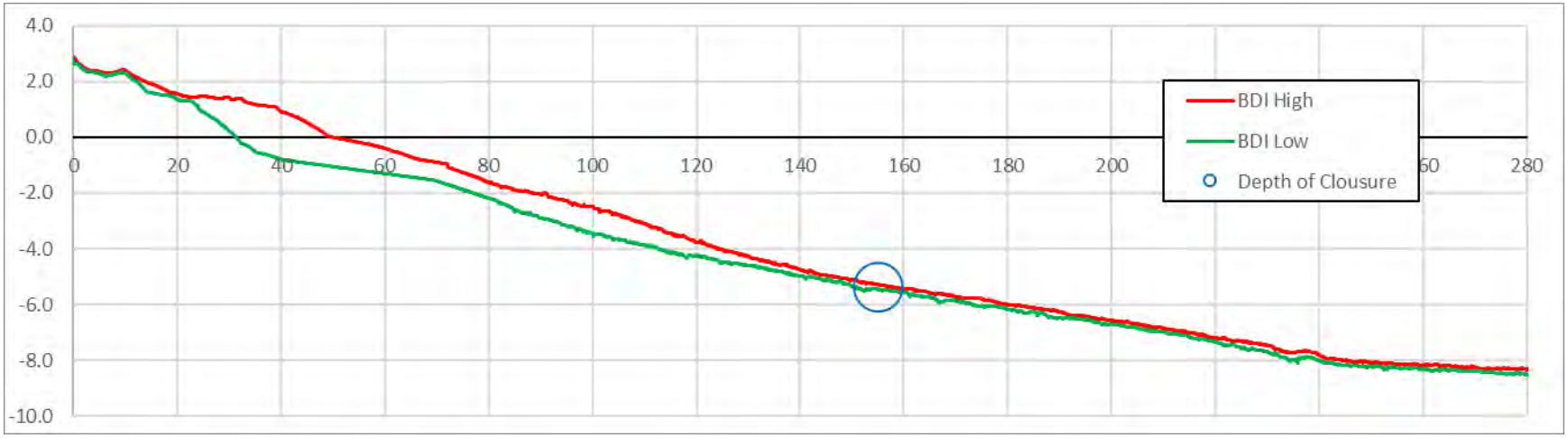

Figure J-134. Envelope of beach profiles and depth of closure at Beach 1 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

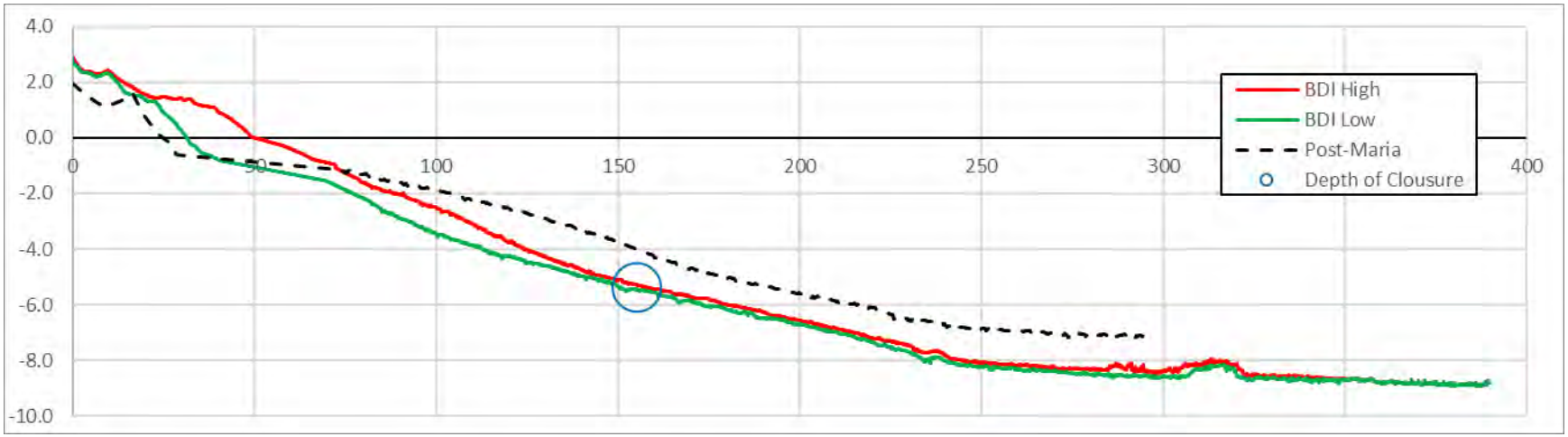

Figure J-135. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 1 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

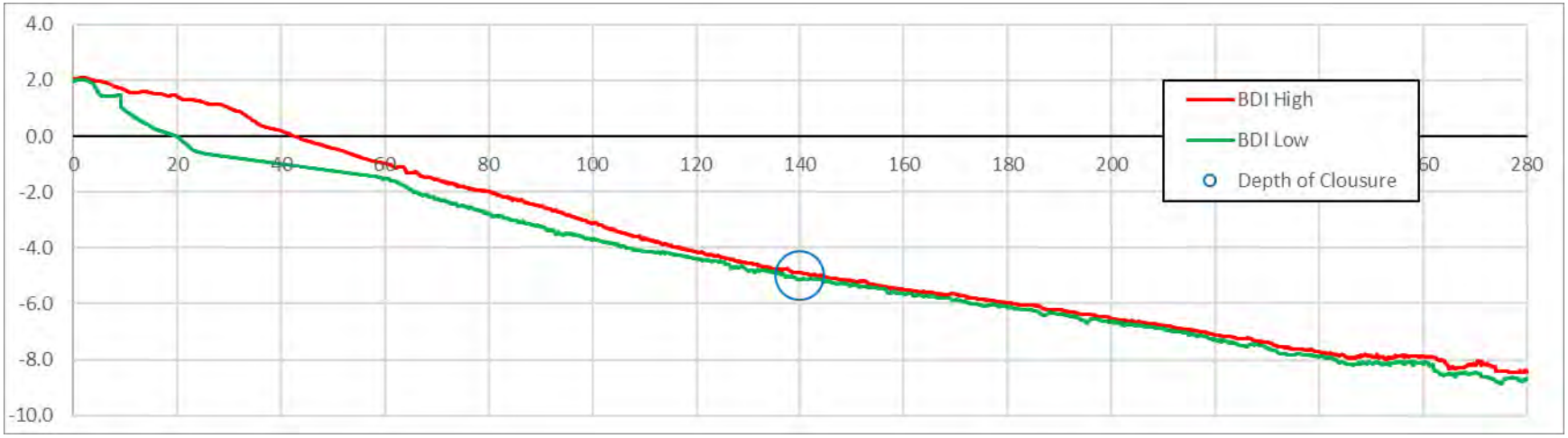

Figure J-136. Envelope of beach profiles and depth of closure at Beach 1 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

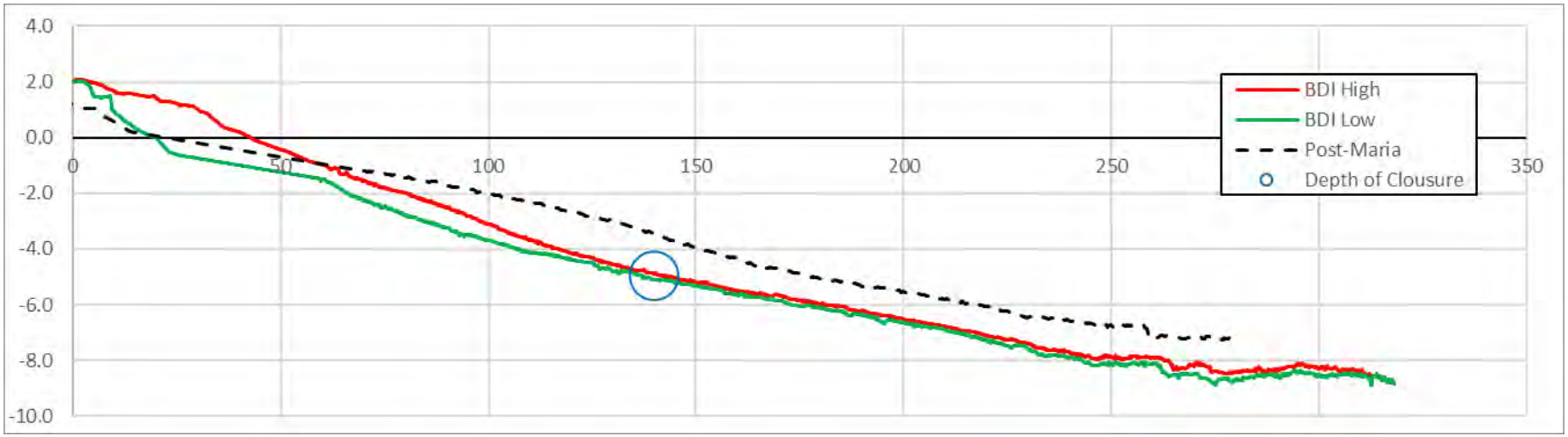

Figure J-137. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 1 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

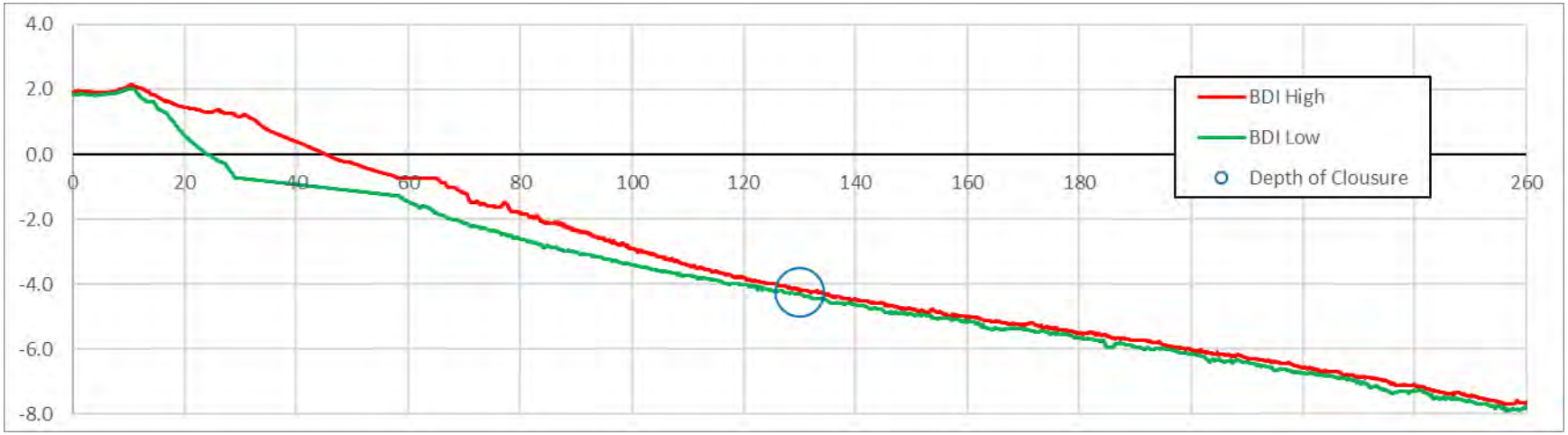

Figure J-138. Envelope of beach profiles and depth of closure at Beach 1 transect 6, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

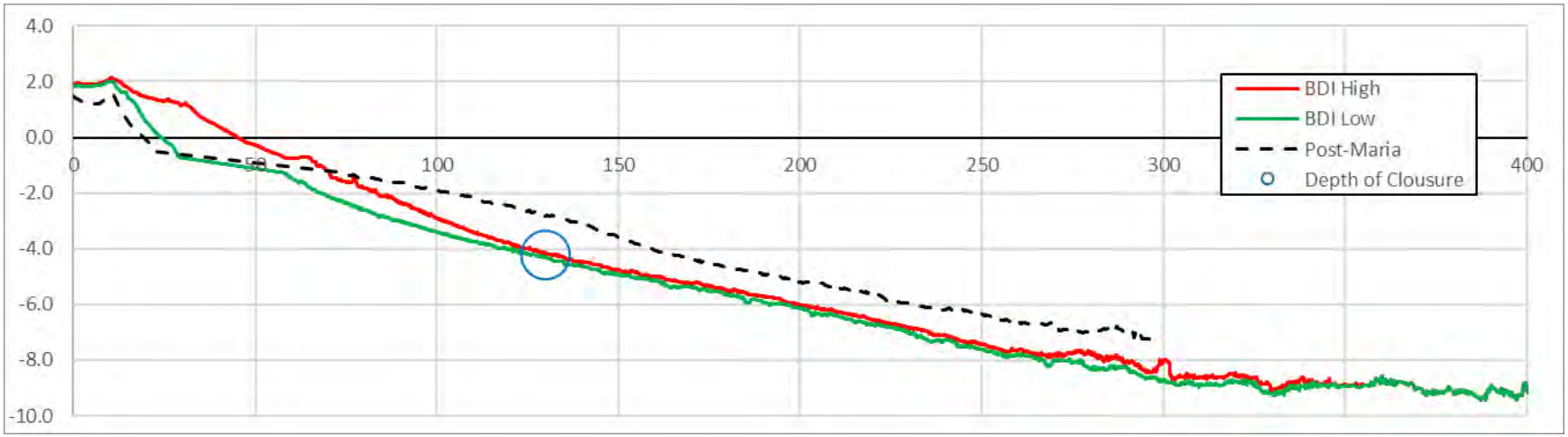

Figure J-139. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 1 transect 6, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

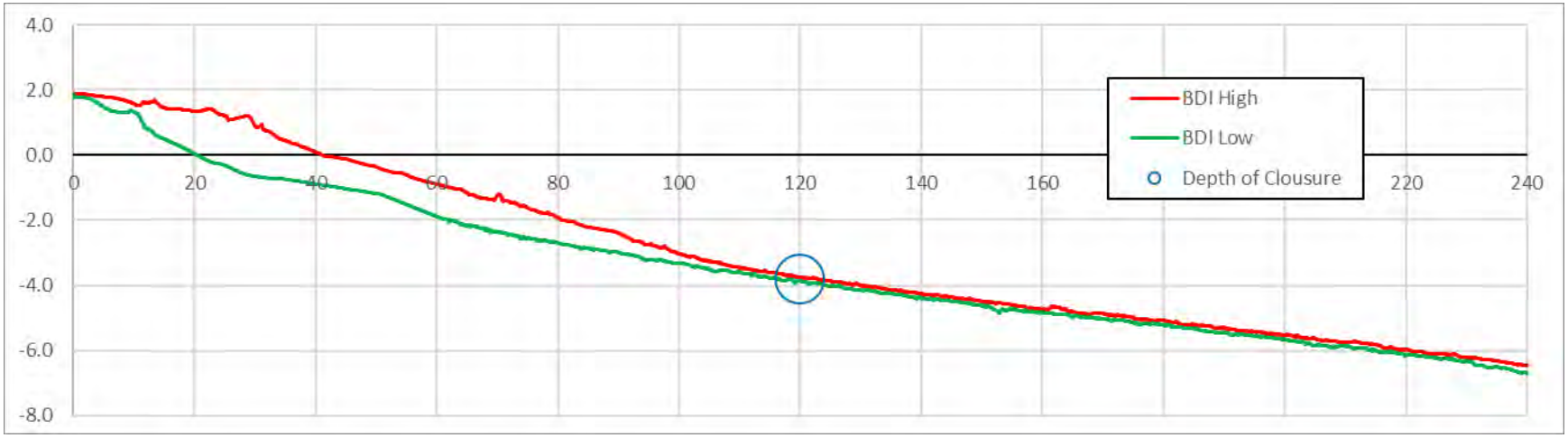

Figure J-140. Envelope of beach profiles and depth of closure at Beach 1 transect 7, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

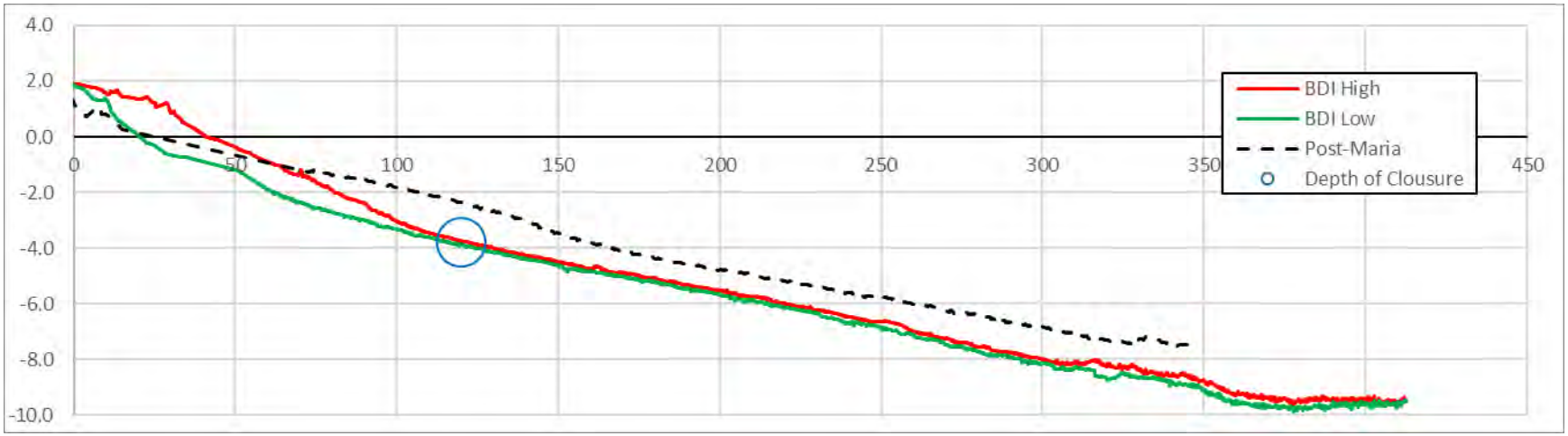

Figure J-141. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 1 transect 7, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

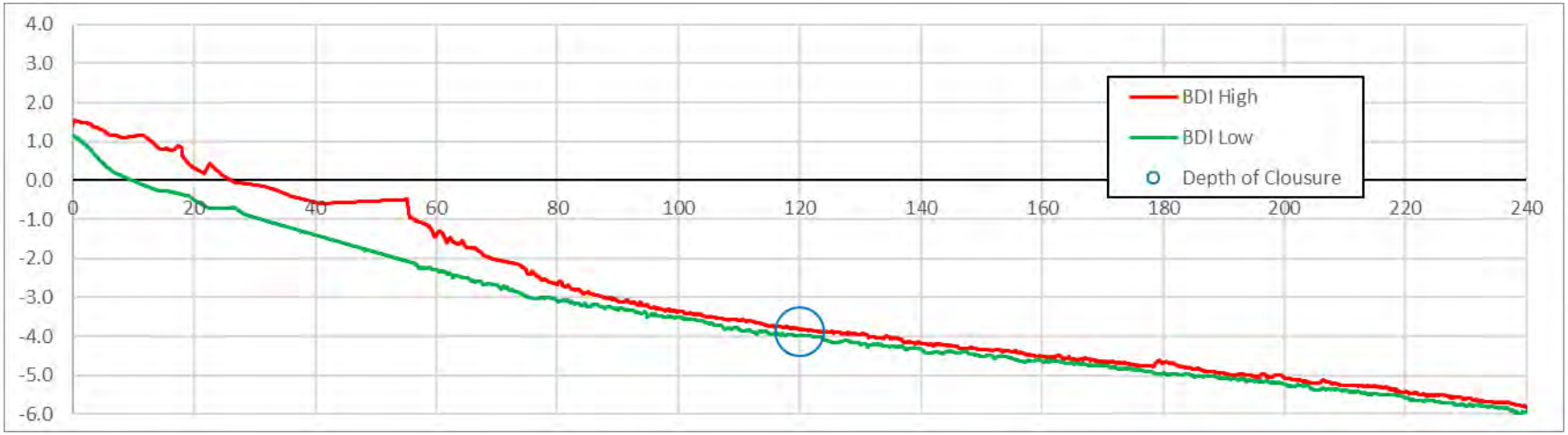

Figure J-142. Envelope of beach profiles and depth of closure at Beach 1 transect 8, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

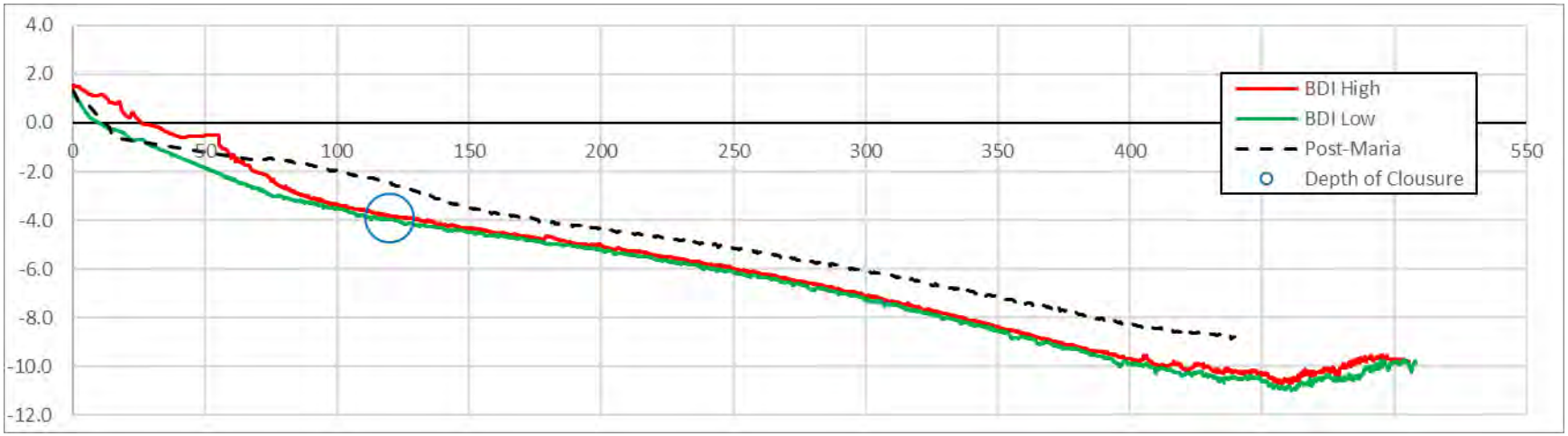

Figure J-143. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 1 transect 8, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

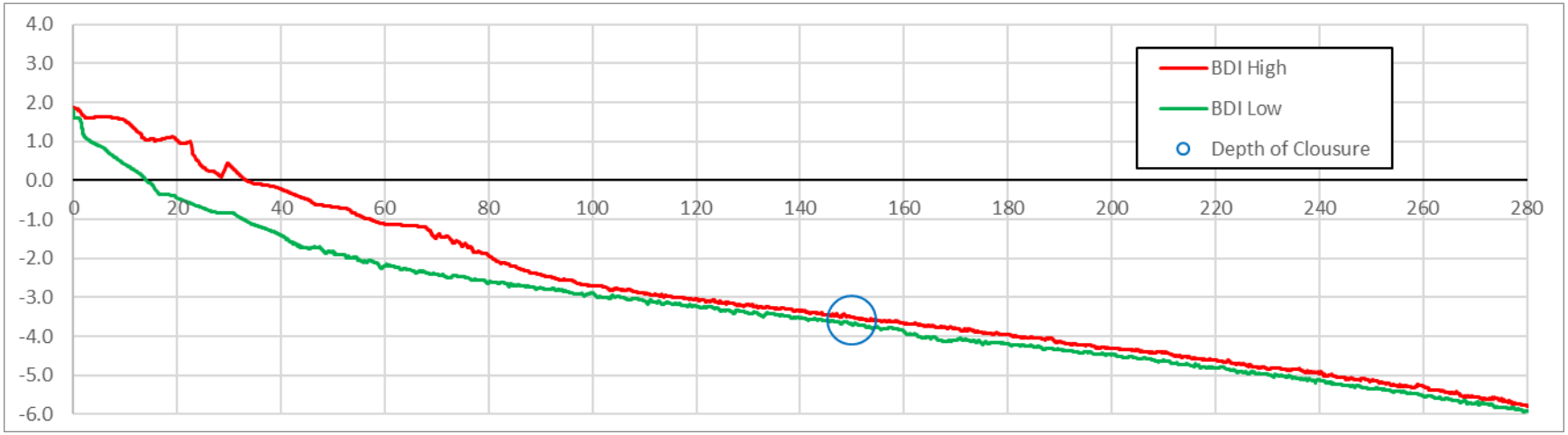

Figure J-144. Envelope of beach profiles and depth of closure at Beach 1 transect 9, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

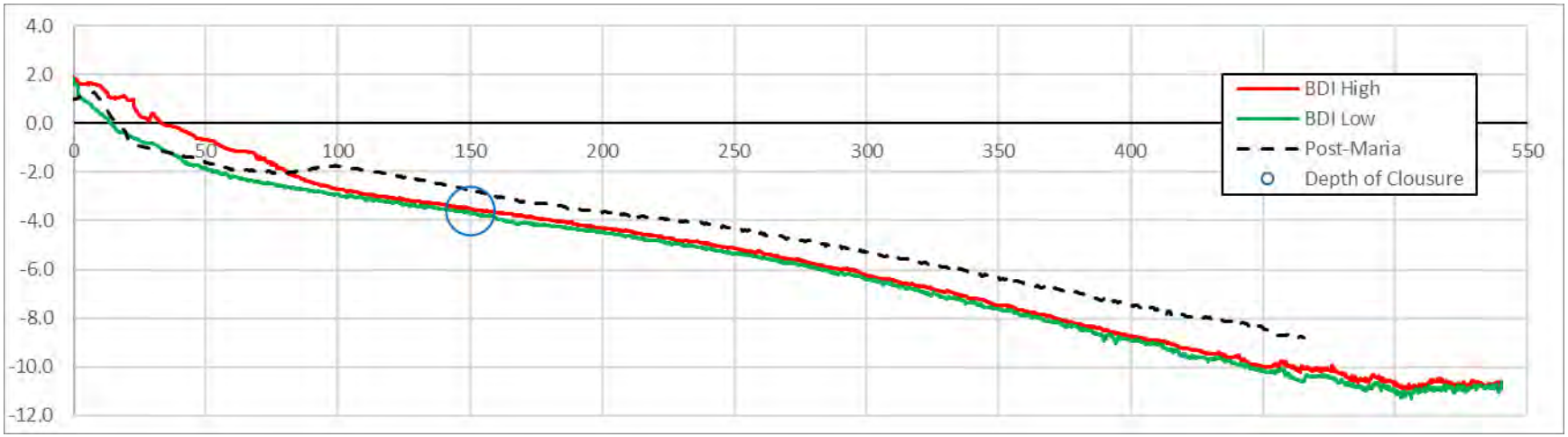

Figure J-145. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 1 transect 9, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Table J-17. Locations of depth of closure and landward limit of beach change, and width of area of beach change during the BDI and Post-Maria for Beach 1.

Transect	Depth of Closure			Landward Limit of Beach Change						Width	
				BDI			Post-Maria				
	Easting	Northing	Depth	Easting	Northing	Elevation	Easting	Northing	Elevation	BDI	Post-Maria
01-01	253,805.6	2,005,317.1	-5.99	253,698.6	2,005,420.9	1.56	253,674.2	2,005,444.5	2.65	149.0	183.0
01-02	253,873.3	2,005,397.4	-5.69	253,781.4	2,005,504.2	1.58	253,756.6	2,005,533.1	3.10	141.0	179.0
01-03	253,937.0	2,005,455.0	-5.50	253,851.6	2,005,559.6	1.51	253,828.8	2,005,587.5	3.00	135.0	171.0
01-04	254,002.1	2,005,505.1	-5.37	253,937.3	2,005,617.8	1.42	253,921.3	2,005,645.5	2.85	130.0	162.0
01-05	254,081.2	2,005,557.7	-4.97	254,026.7	2,005,677.1	1.67	254,021.0	2,005,689.6	2.00	131.3	145.0
01-06	254,169.8	2,005,613.0	-4.24	254,127.7	2,005,721.4	1.87	254,121.8	2,005,736.6	1.90	116.2	132.5
01-07	254,255.9	2,005,652.8	-3.81	254,229.3	2,005,760.9	1.68	254,226.2	2,005,773.7	1.85	111.3	124.5
01-08	254,361.8	2,005,669.5	-3.89	254,348.8	2,005,788.8	1.21	254,348.8	2,005,788.8	1.40	120.0	120.0
01-09	254,479.1	2,005,664.2	-3.59	254,485.3	2,005,812.8	1.60	254,486.0	2,005,831.1	1.80	148.7	167.0

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
Depth of closure and elevations of landward limit of beach change relative to PRVD02
Width (of the area of beach change) = horizontal distance along the transect between the depth of closure and landward limit of beach change

Table J-18. Locations of maximum beach elevation change, ranges, and high and low elevations of envelope for Beach 1.

Transect	Easting	Northing	Range	High	Low
01-01	253,708.3	2,005,411.5	1.56	1.25	-0.31
01-02	253,792.4	2,005,491.5	1.61	1.11	-0.50
01-03	253,858.2	2,005,551.5	1.58	1.35	-0.23
01-04	253,944.3	2,005,605.6	1.83	1.10	-0.73
01-05	254,034.6	2,005,659.7	1.84	1.15	-0.69
01-06	254,133.9	2,005,705.6	1.98	1.23	-0.75
01-07	254,234.1	2,005,741.3	1.84	1.22	-0.62
01-08	254,354.8	2,005,734.0	1.58	-0.49	-2.07
01-09	254,484.4	2,005,791.5	1.59	1.00	-0.59

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
High and low elevations relative to PRVD02

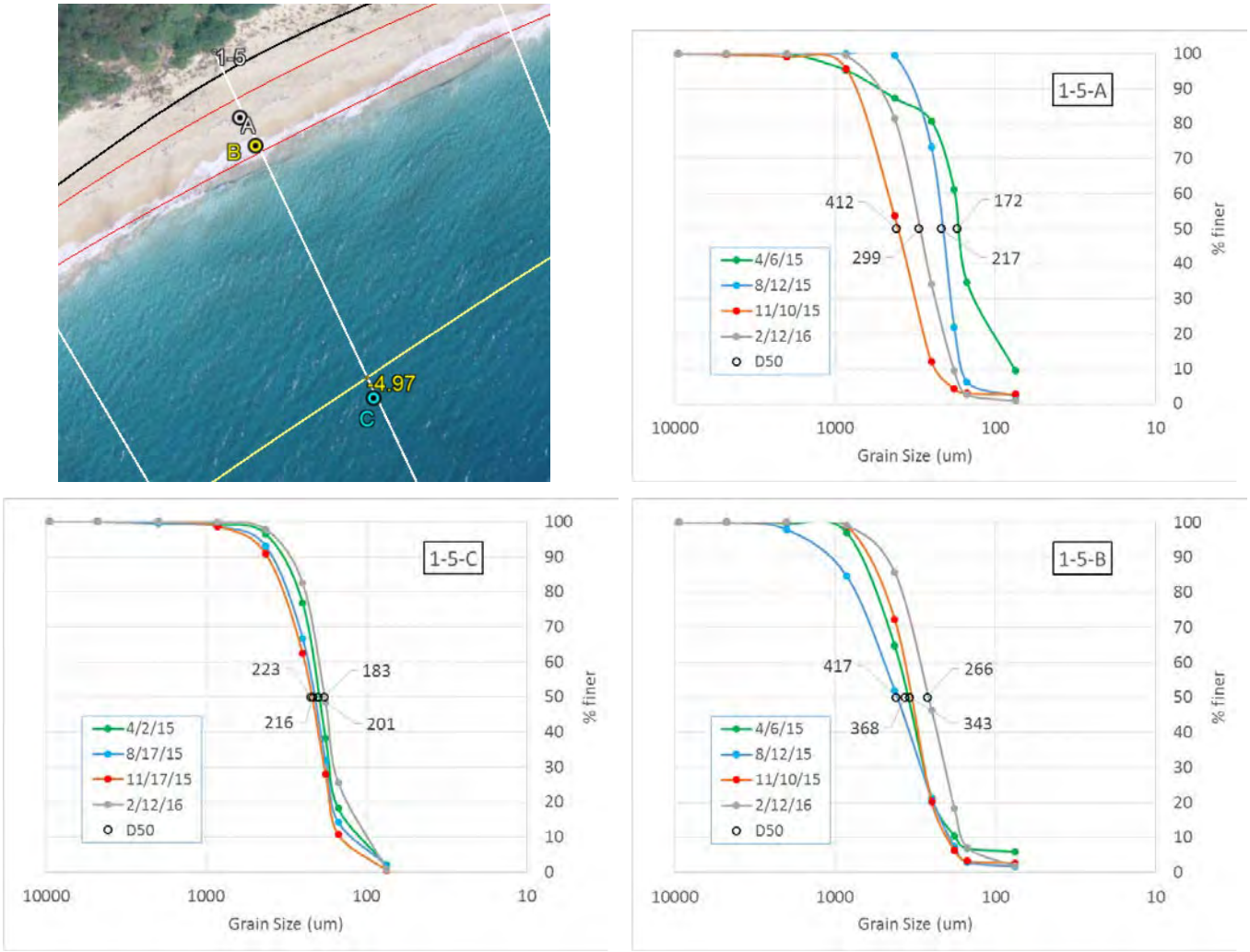

Figure J-146. Clockwise from top: approximate locations of sediment samples at Beach 1, BDI landward limit of beach change, maximum landward and seaward shoreline positions, depth of closure; and distribution of grain size at backshore (A), shoreline (B) and nearshore (C) locations.

South SIA UXO 8
Beach 19

Figure J-147. Beach 19 transects, bathymetry and coastal features.

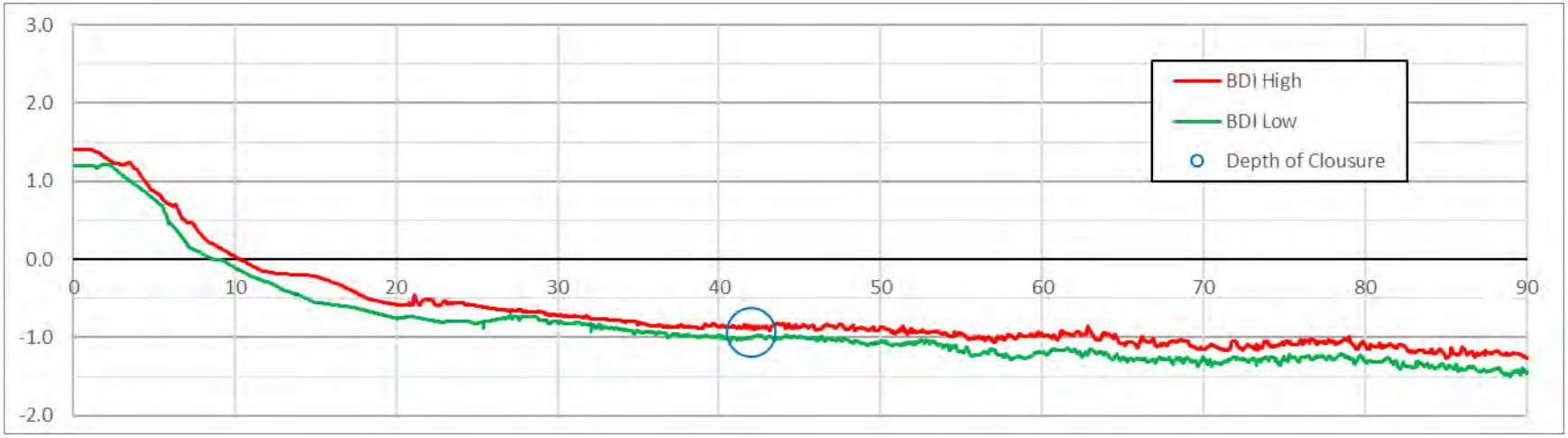

Figure J-148. Envelope of beach profiles and depth of closure at Beach 19 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

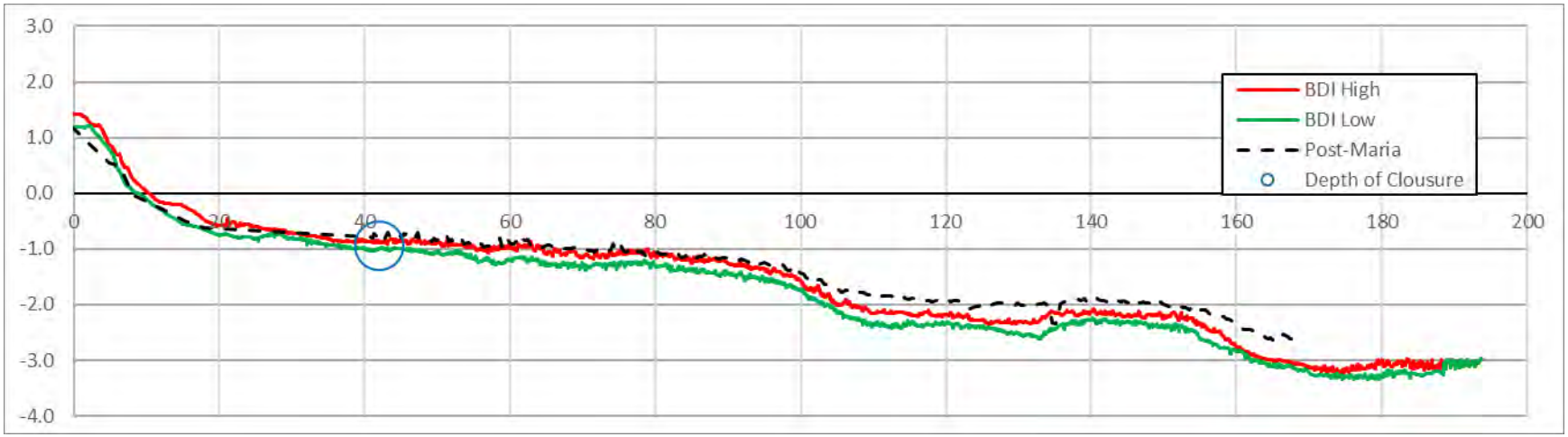

Figure J-149. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 19 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

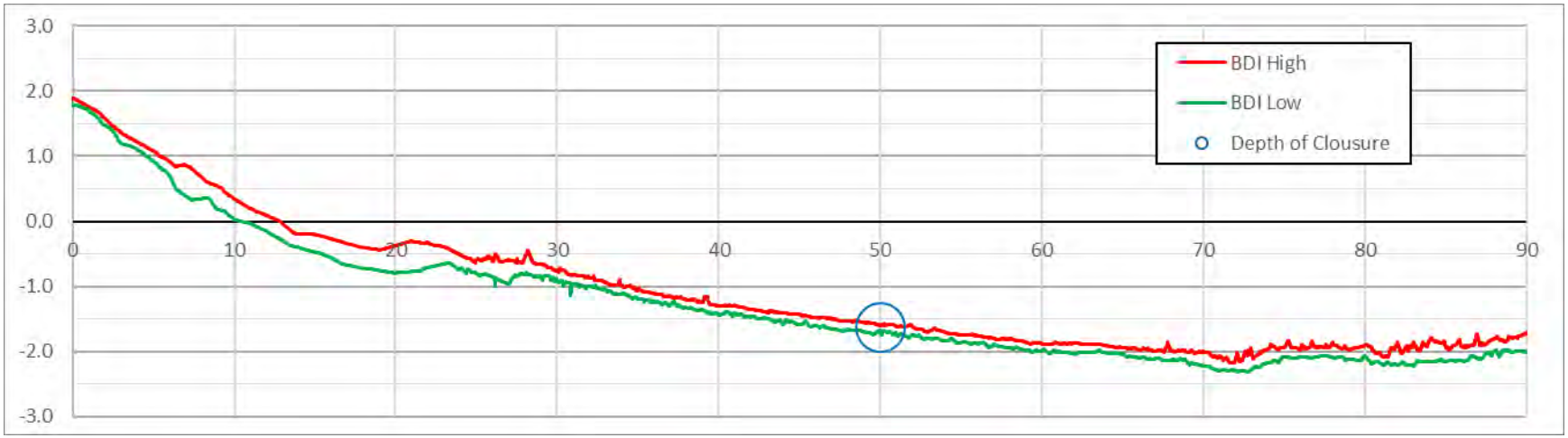

Figure J-150. Envelope of beach profiles and depth of closure at Beach 19 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

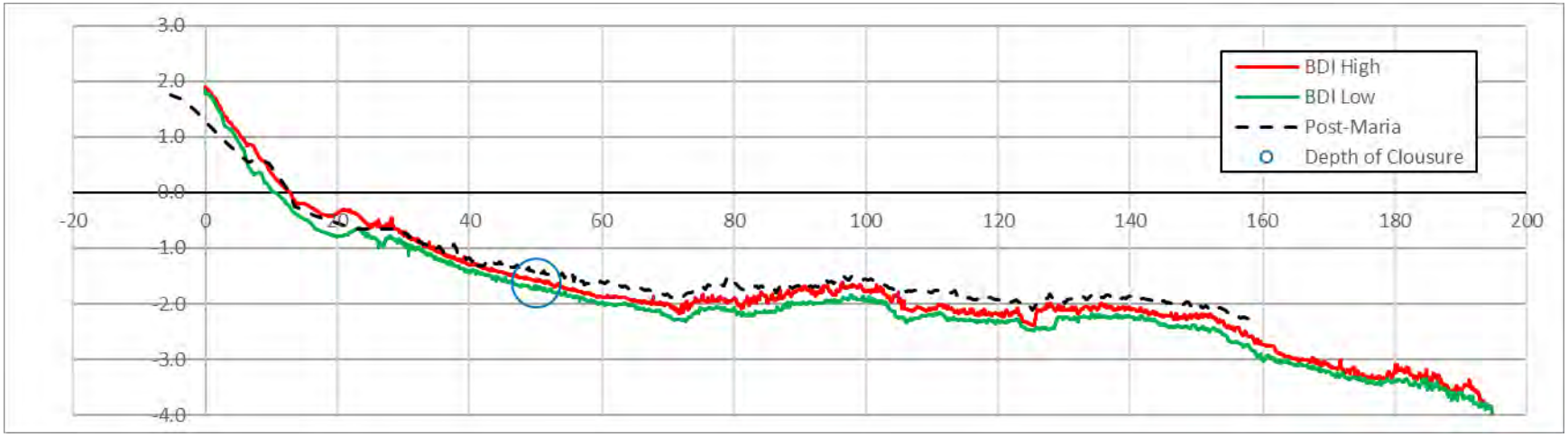

Figure J-151. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 19 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

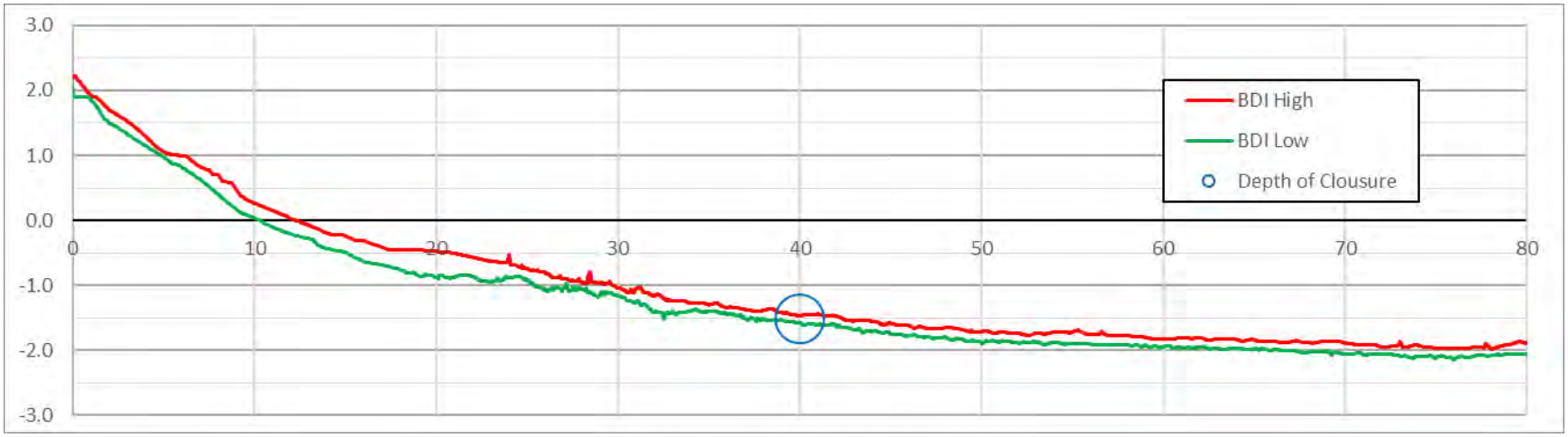

Figure J-152. Envelope of beach profiles and depth of closure at Beach 19 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

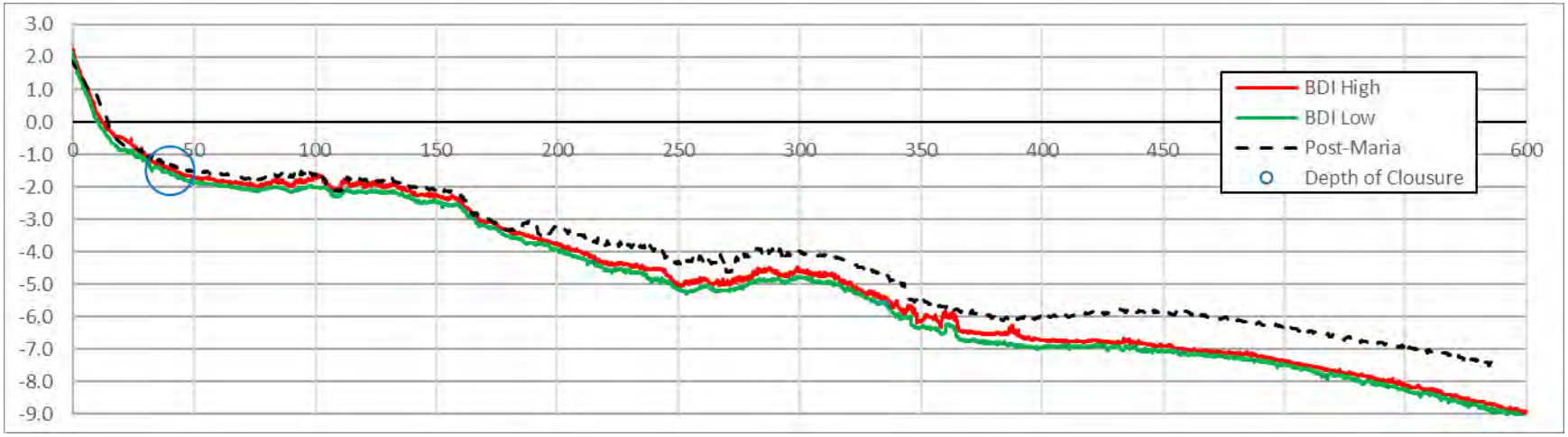

Figure J-153. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 19 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

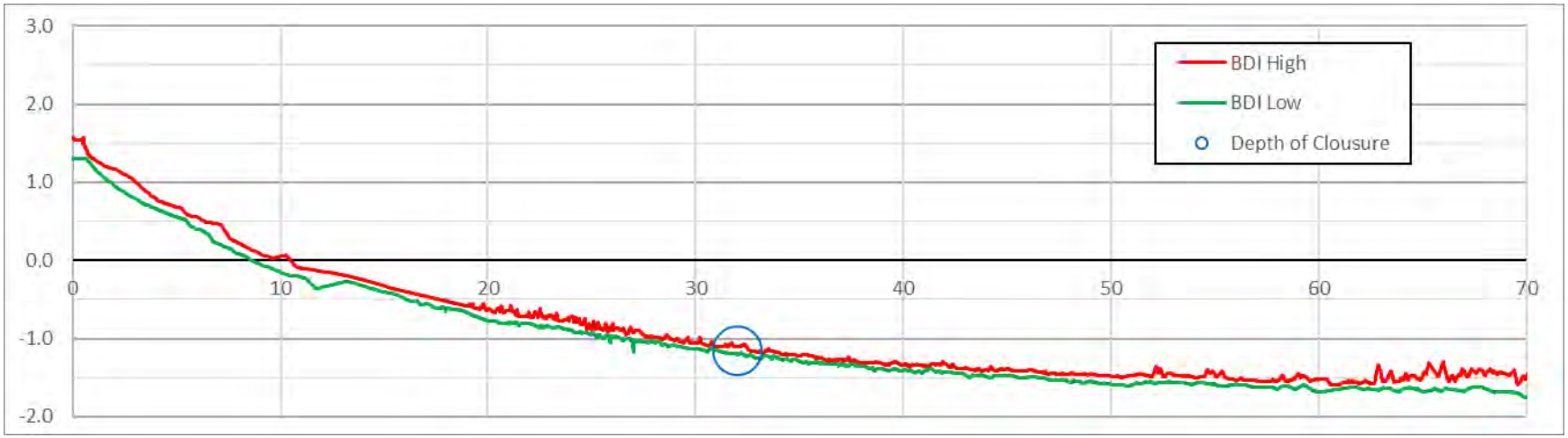

Figure J-154. Envelope of beach profiles and depth of closure at Beach 19 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

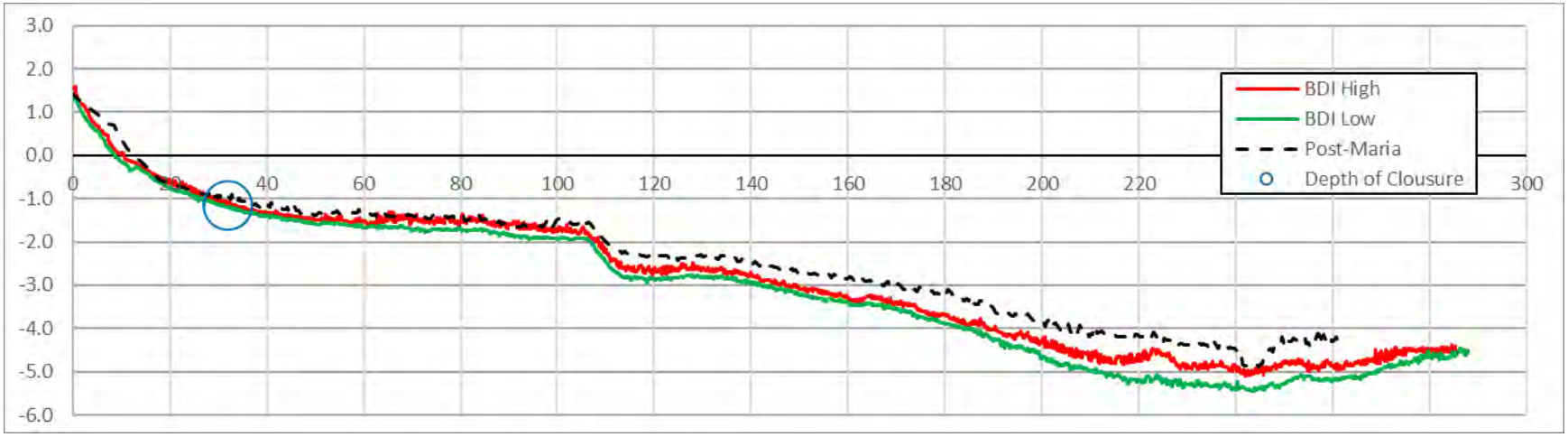

Figure J-155. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 19 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

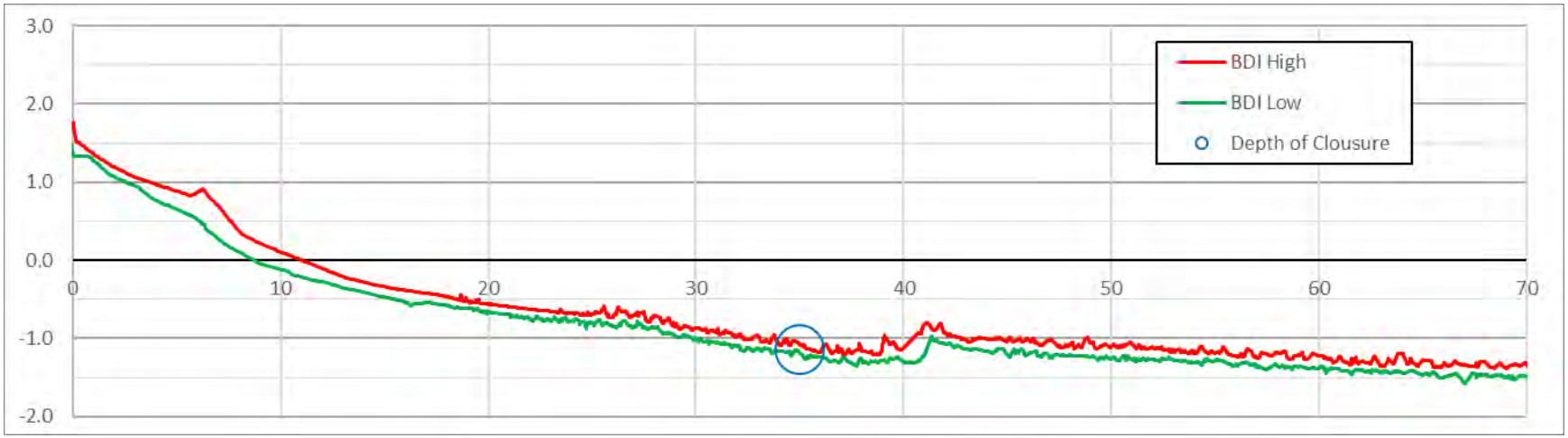

Figure J-156. Envelope of beach profiles and depth of closure at Beach 19 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

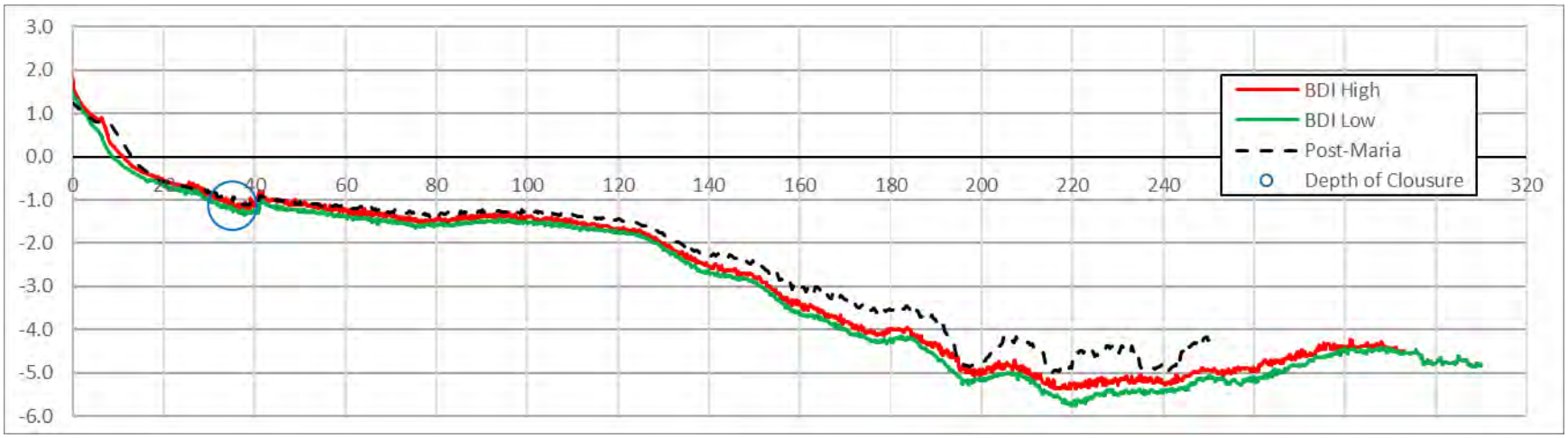

Figure J-157. Envelope of beach profiles, post-Maria profile and depth of closure at Beach 19 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Table J-19. Locations of depth of closure and landward limit of beach change, and width of area of beach change during the BDI and Post-Maria for Beach 19.

Transect	Depth of Closure			Landward Limit of Beach Change						Width	
				BDI			Post-Maria				
	Easting	Northing	Depth	Easting	Northing	Elevation	Easting	Northing	Elevation	BDI	Post-Maria
19-01	252,517.0	2,004,964.6	-0.94	252,480.3	2,004,961.3	0.76	252,473.7	2,004,960.8	1.30	36.8	43.5
19-02	252,532.7	2,005,013.1	-1.63	252,490.7	2,005,030.3	1.01	252,481.7	2,005,034.1	1.76	45.4	55.2
19-03	252,562.9	2,005,064.2	-1.51	252,542.5	2,005,092.5	1.00	252,535.9	2,005,101.7	2.57	34.9	46.3
19-04	252,598.2	2,005,084.6	-1.15	252,586.8	2,005,108.8	0.59	252,581.6	2,005,119.9	2.25	26.7	39.0
19-05	252,640.2	2,005,093.6	-1.14	252,632.4	2,005,124.9	1.05	252,630.0	2,005,134.4	2.14	32.3	42.1

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
Depth of closure and elevations of landward limit of beach change relative to PRVD02
Width (of the area of beach change) = horizontal distance along the transect between the depth of closure and landward limit of beach change

Table J-20. Locations of maximum beach elevation change, ranges, and high and low elevations of envelope for Beach 19.

Transect	Easting	Northing	Range	High	Low
19-01	252,482.5	2,004,961.5	0.34	0.47	0.13
19-02	252,493.2	2,005,029.3	0.49	0.83	0.34
19-03	252,550.7	2,005,081.0	0.41	-0.46	-0.87
19-04	252,587.6	2,005,107.1	0.26	0.46	0.20
19-05	252,633.3	2,005,121.3	0.46	0.87	0.40

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
High and low elevations relative to PRVD02

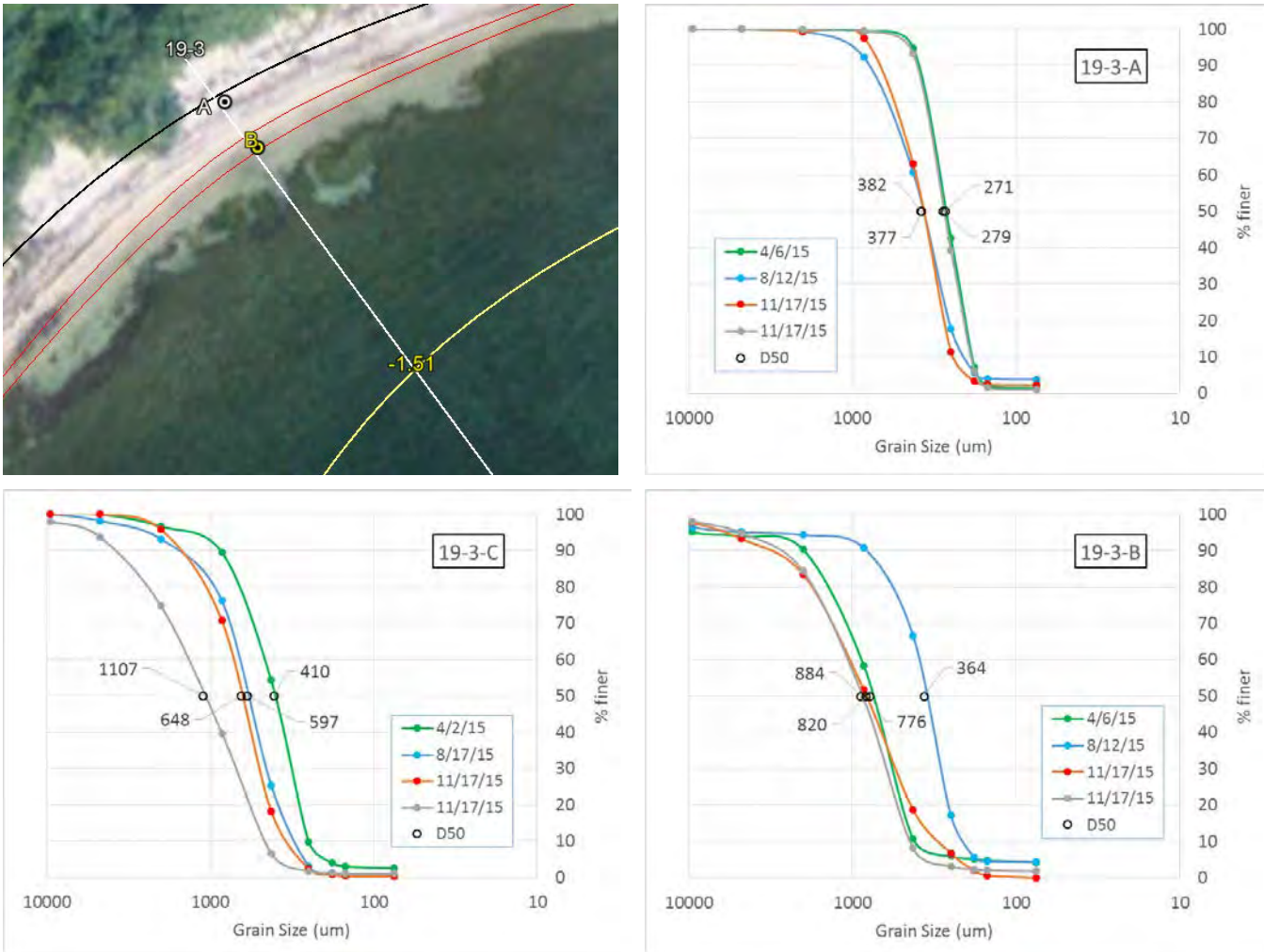

Figure J-158. Clockwise from top: approximate locations of sediment samples at Beach 19 (location C offshore omitted for clarity), BDI landward limit of beach change, maximum landward and seaward shoreline positions, depth of closure; and distribution of grain size at backshore (A), shoreline (B) and nearshore (C) locations.

SWMU 4

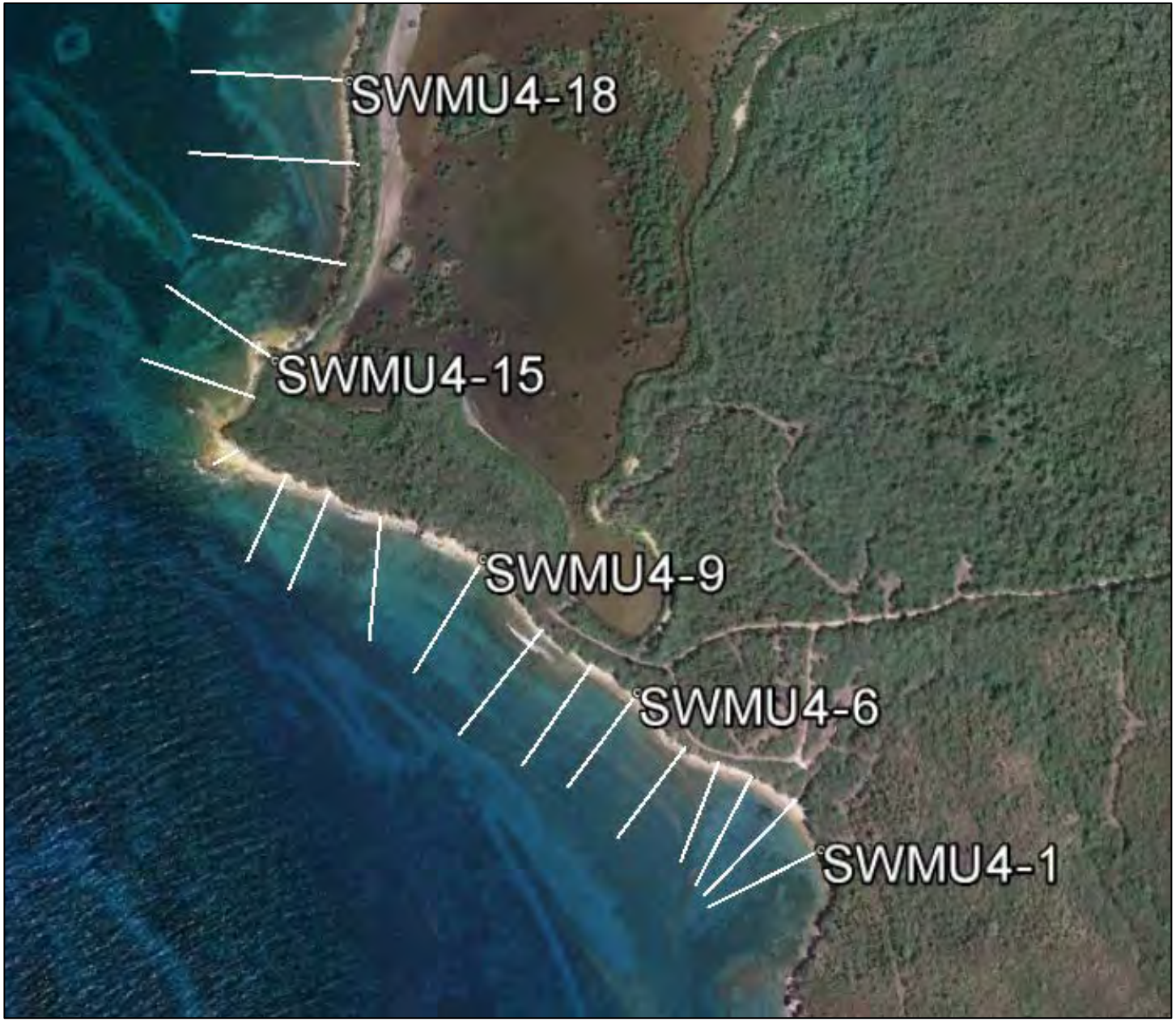

Figure J-159. SWMU 4 transects, bathymetry and coastal features.

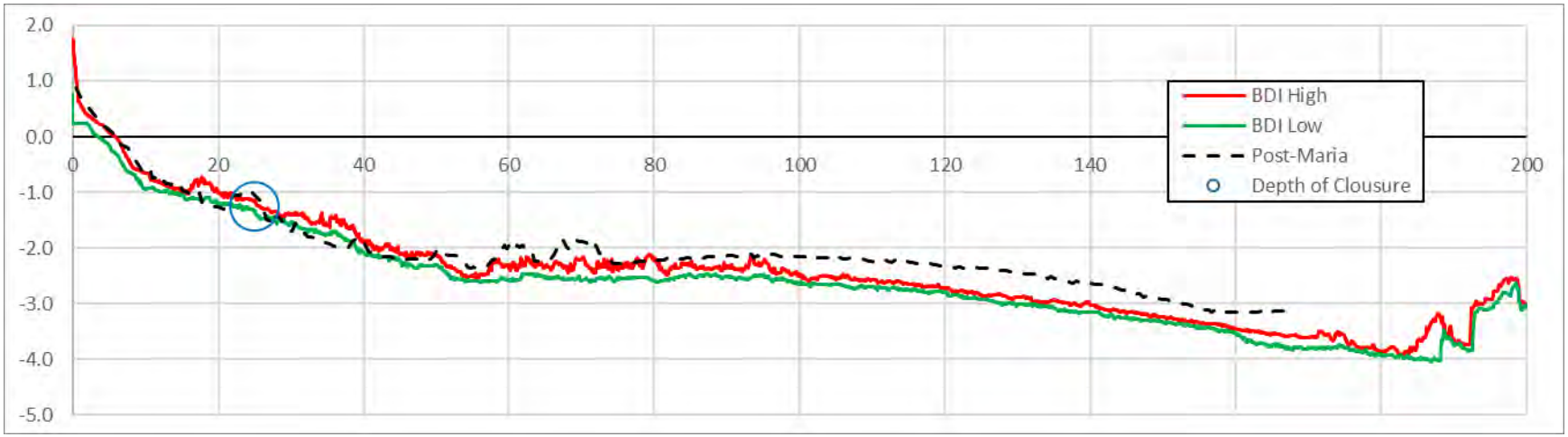

Figure J-160. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 1, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

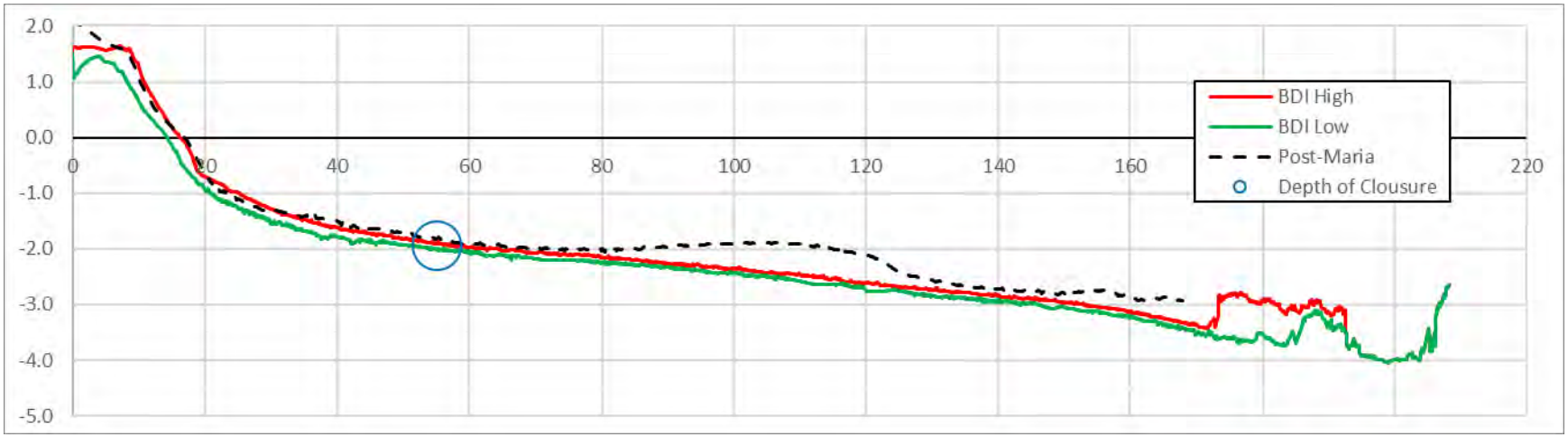

Figure J-161. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 2, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

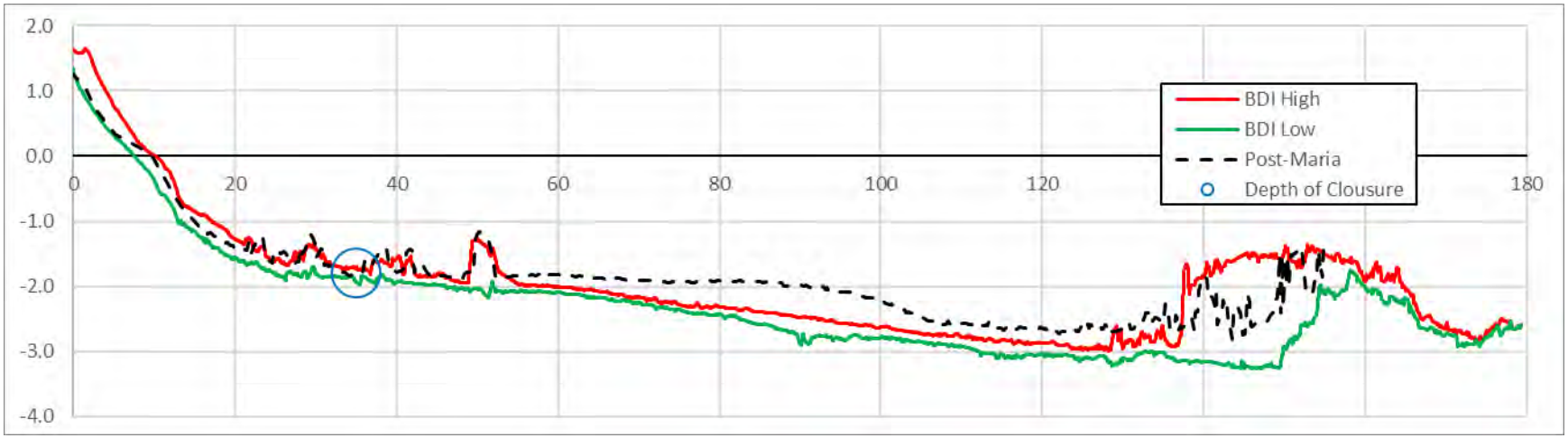

Figure J-162. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 3, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

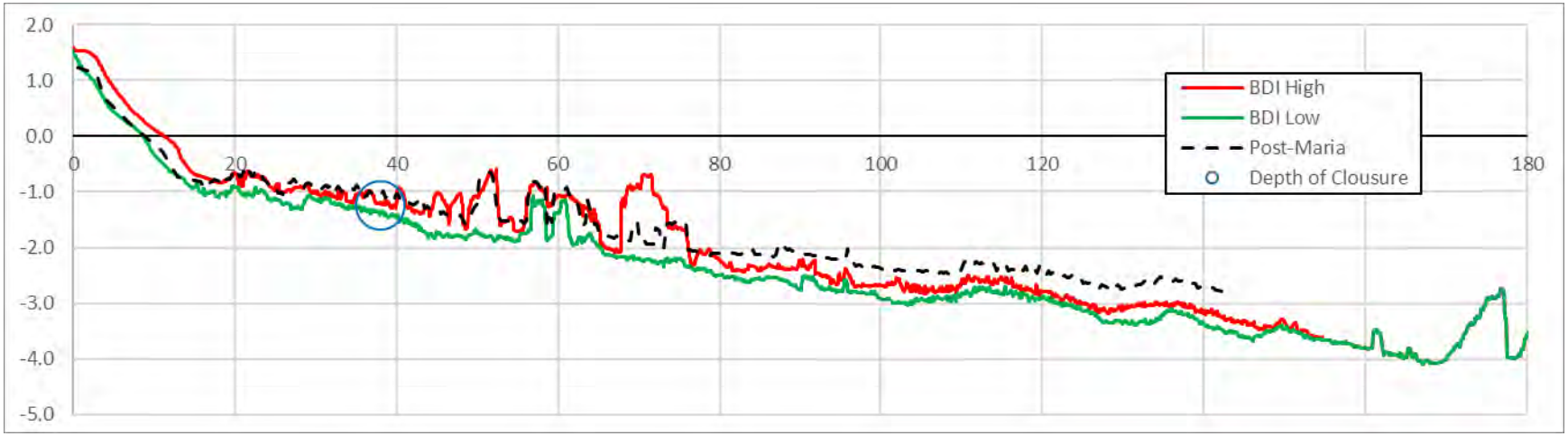

Figure J-163. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 4, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

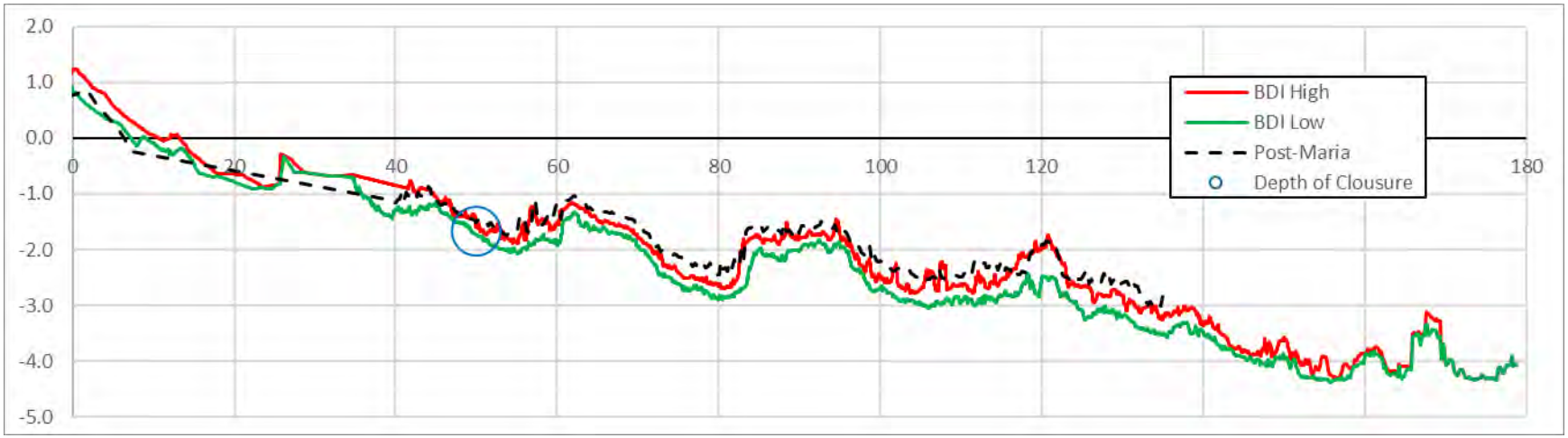

Figure J-164. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 5, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

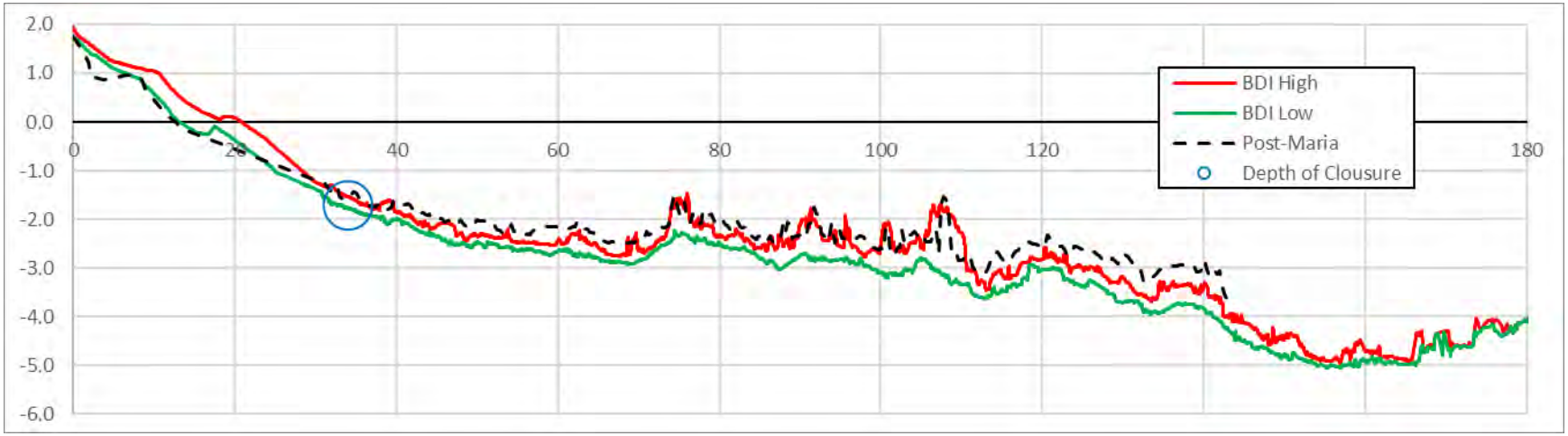

Figure J-165. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 6, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

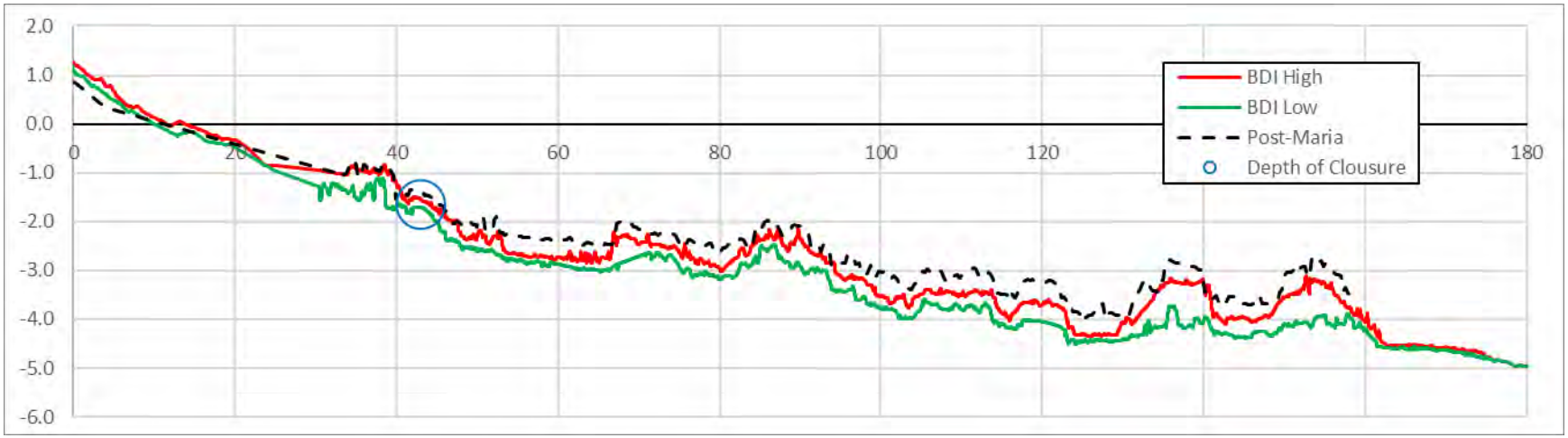

Figure J-166. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 7, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

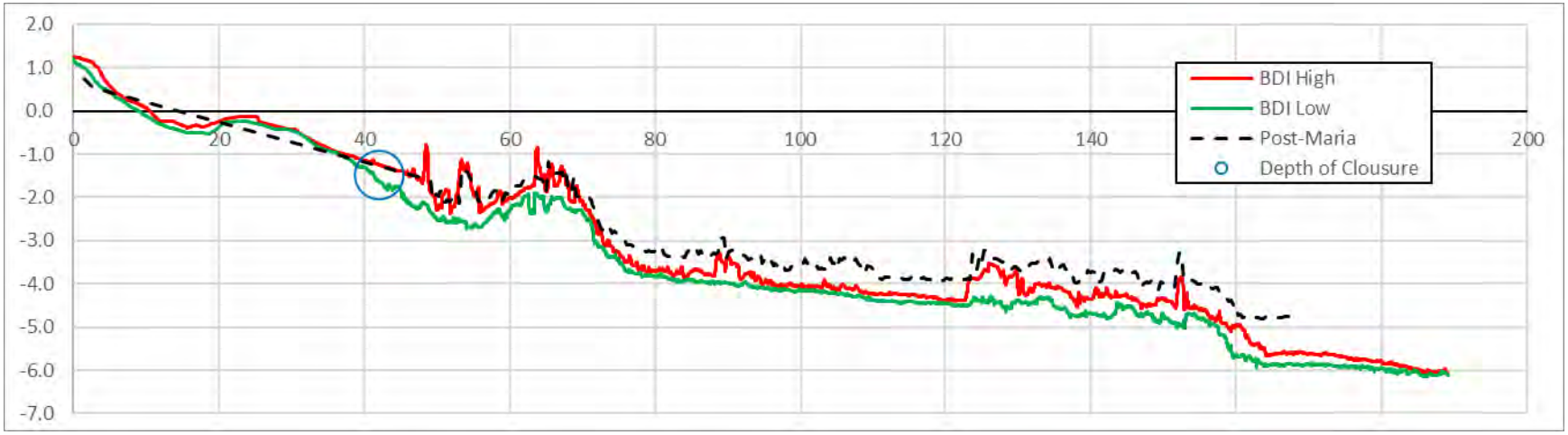

Figure J-167. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 8, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Figure J-168. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 9, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

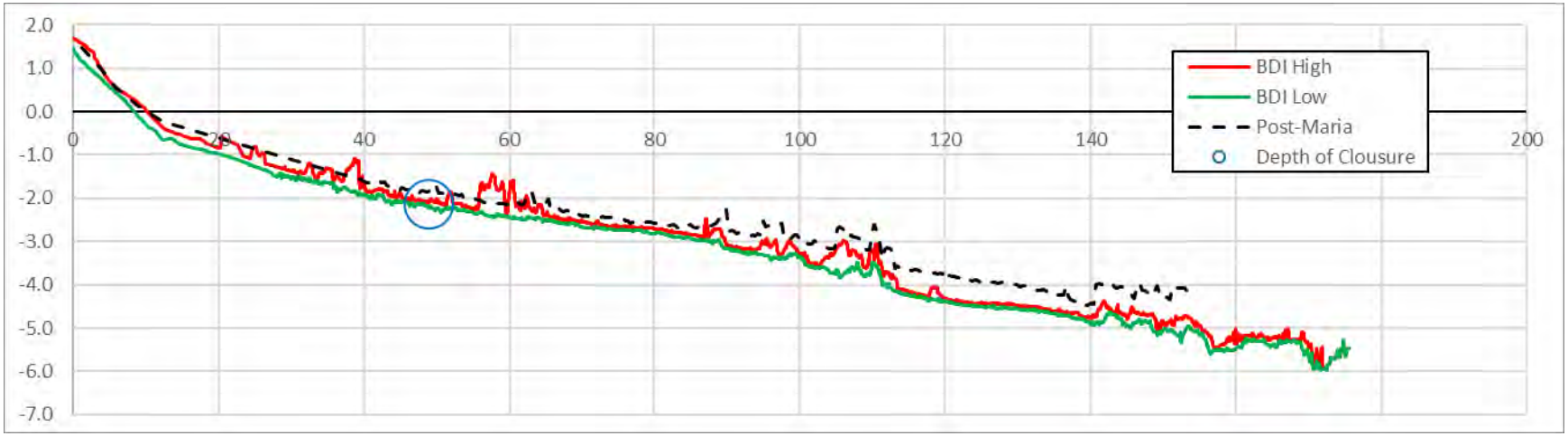

Figure J-169. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 10, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

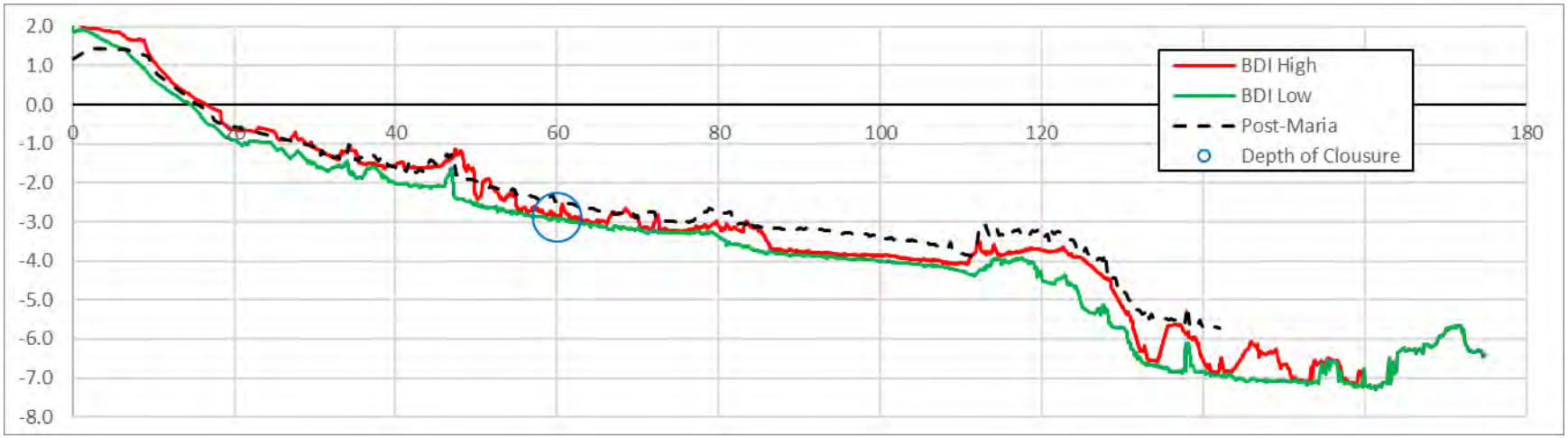

Figure J-170. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 11, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Figure J-171. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 12, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

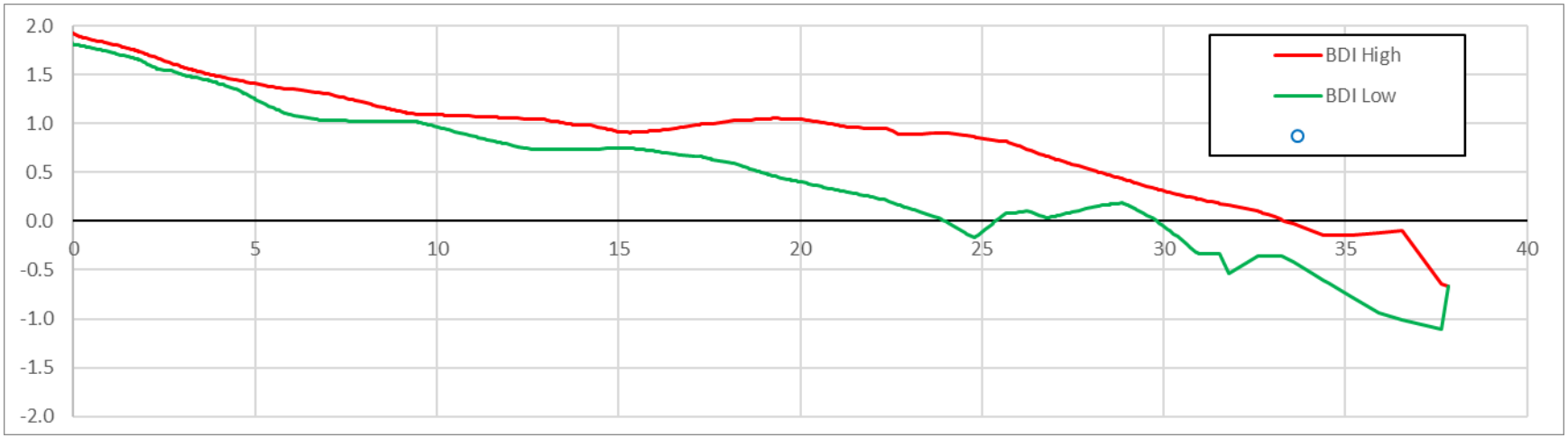

Figure J-172. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 13, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

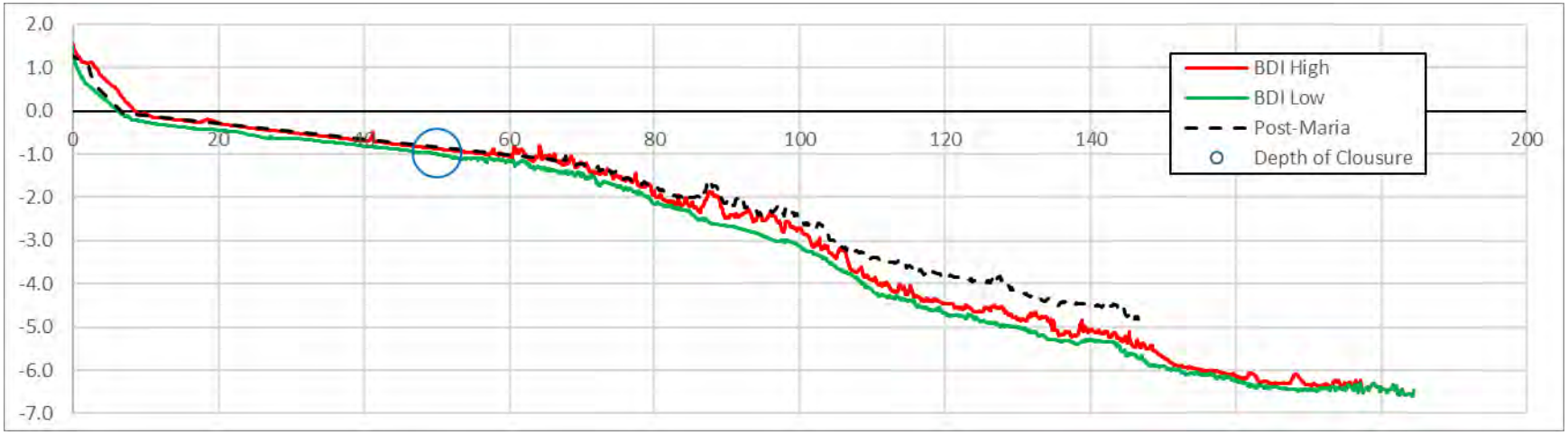

Figure J-173. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 14, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

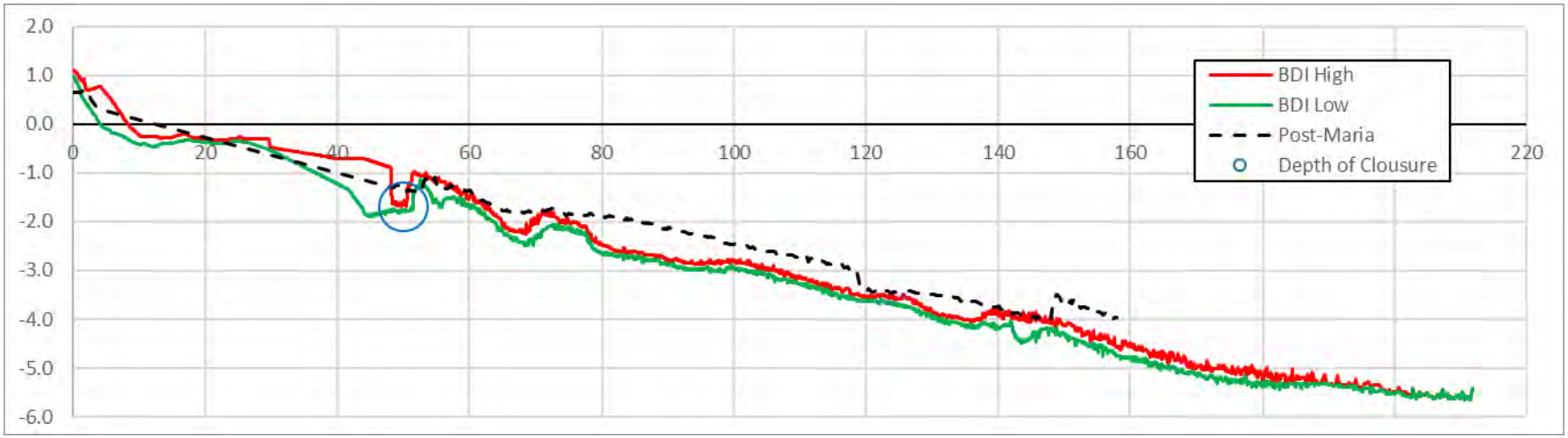

Figure J-174. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 15, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

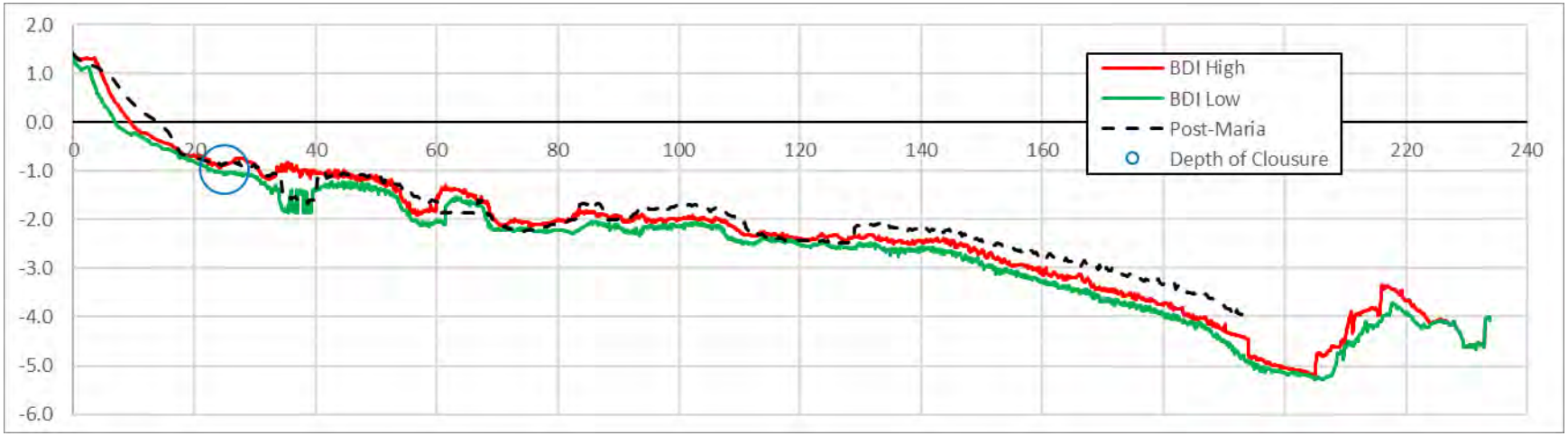

Figure J-175. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 16, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

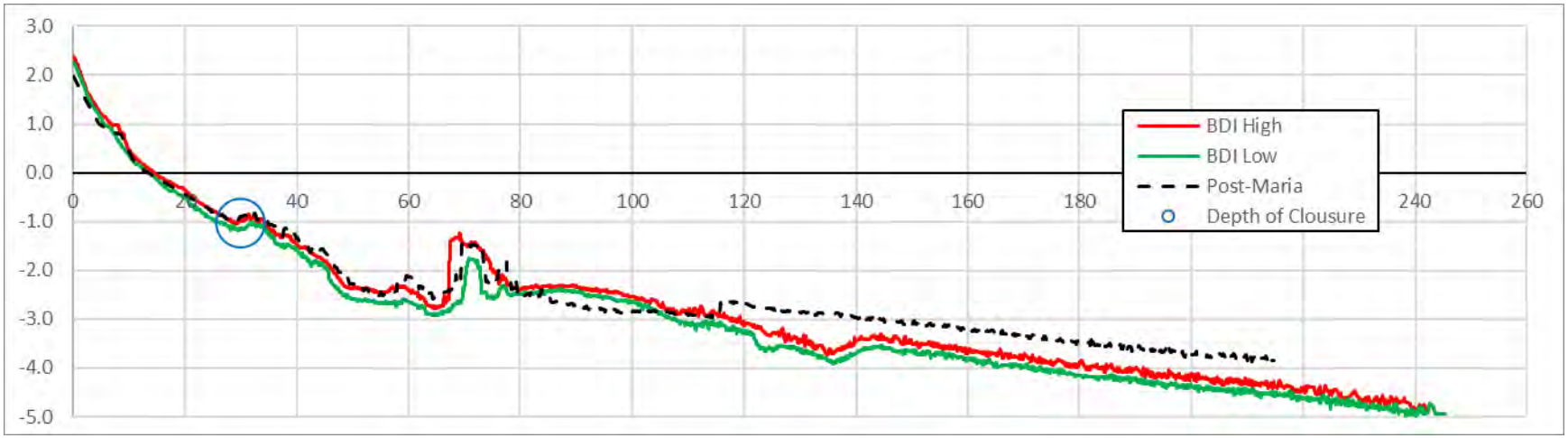

Figure J-176. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 17, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

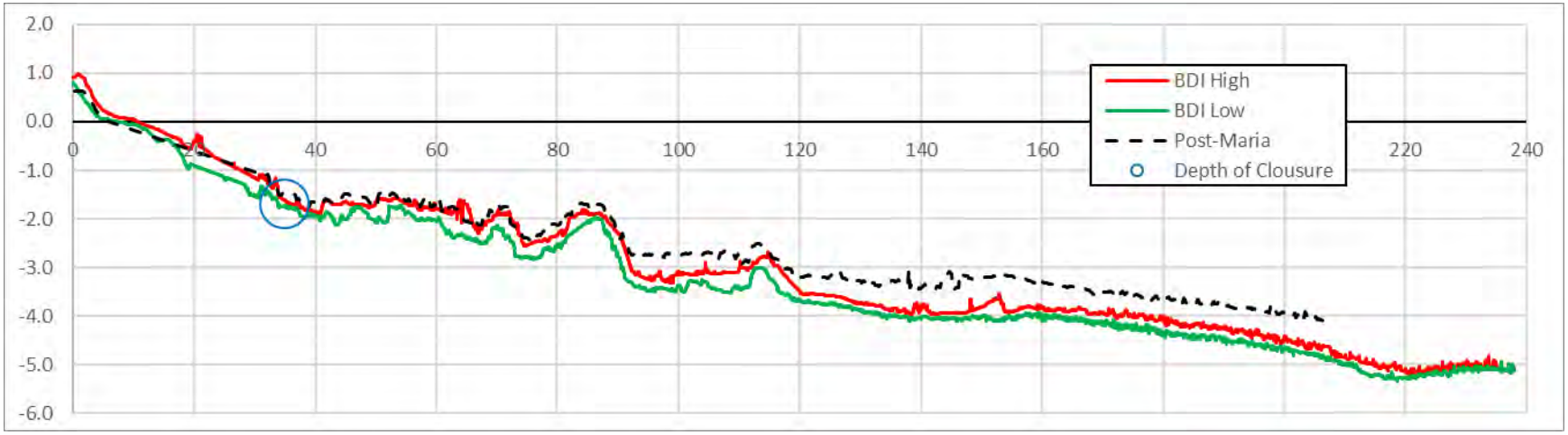

Figure J-177. Envelope of beach profiles, post-Maria profile and depth of closure at SWMU 4 transect 18, elevation (m, PRVD02) versus cross-shore distance (m from transect head).

Table J-21. Locations of depth of closure and landward limit of beach change, and width of area of beach change during the BDI and Post-Maria for SWMU 4 (southwest-facing).

Transect	Depth of Closure			Landward Limit of Beach Change						Width	
				BDI			Post-Maria				
	Easting	Northing	Depth	Easting	Northing	Elevation	Easting	Northing	Elevation	BDI	Post-Maria
S4-01	227,898.1	2,002,933.5	-1.24	227,917.8	2,002,943.2	0.25	227,922.3	2,002,945.4	1.18	22.0	26.9
S4-02	227,852.6	2,002,966.1	-1.95	227,888.1	2,003,001.8	1.53	227,891.5	2,003,005.2	2.13	50.4	55.2
S4-03	227,821.8	2,003,003.7	-1.80	227,838.3	2,003,034.5	1.43	227,839.9	2,003,037.5	1.41	35.0	38.3
S4-04	227,784.3	2,003,016.4	-1.24	227,798.4	2,003,051.5	1.51	227,799.4	2,003,053.8	1.25	37.9	40.4
S4-05	227,728.3	2,003,030.5	-1.68	227,759.0	2,003,070.0	1.00	227,760.7	2,003,072.2	0.89	50.0	52.9
S4-06	227,681.7	2,003,108.8	-1.71	227,697.6	2,003,129.5	1.00	227,702.4	2,003,135.7	1.75	26.1	34.0
S4-07	227,621.5	2,003,134.0	-1.64	227,642.8	2,003,163.8	0.36	227,648.3	2,003,171.4	1.20	36.6	46.0
S4-08	227,561.7	2,003,180.4	-1.47	227,588.3	2,003,212.9	1.18	227,590.9	2,003,216.0	1.14	42.0	46.0
S4-09	227,498.9	2,003,266.8	-2.10	227,517.7	2,003,296.3	1.52	227,520.9	2,003,301.4	1.80	35.0	41.0
S4-10	227,390.2	2,003,303.0	-2.14	227,395.5	2,003,351.8	1.65	227,395.1	2,003,348.3	1.09	49.0	45.5
S4-11	227,311.0	2,003,327.1	-2.89	227,332.0	2,003,374.9	1.59	227,335.1	2,003,382.0	1.17	52.2	60.0
S4-12	227,267.5	2,003,370.0	-1.61	227,280.3	2,003,396.9	1.59	227,282.9	2,003,402.5	1.10	29.7	36.0
S4-13				227,221.2	2,003,430.1	1.39	227,223.6	2,003,431.4	0.00		

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
Depth of closure and elevations of landward limit of beach change relative to PRVD02
Width (of the area of beach change) = horizontal distance along the transect between the depth of closure and landward limit of beach change

Table JError! No text of specified style in document.-22. Locations of depth of closure and landward limit of beach change, and width of area of beach change during the BDI and Post-Maria for SWMU 4 (west-facing).

Transect	Depth of Closure			Landward Limit of Beach Change						Width	
				BDI			Post-Maria				
	Easting	Northing	Depth	Easting	Northing	Elevation	Easting	Northing	Elevation	BDI	Post-Maria
S4-14	227,198.6	2,003,511.8	-0.99	227,245.2	2,003,495.3	1.02	227,245.2	2,003,495.3	1.02	49.4	49.4
S4-15	227,230.8	2,003,567.8	-1.70	227,270.7	2,003,539.9	0.66	227,271.9	2,003,539.0	0.64	48.6	50.1
S4-16	227,333.1	2,003,657.3	-0.98	227,354.9	2,003,652.8	1.21	227,354.9	2,003,652.8	1.21	22.2	22.2
S4-17	227,345.5	2,003,775.1	-1.04	227,368.2	2,003,773.3	0.90	227,368.2	2,003,773.3	0.90	22.7	22.7
S4-18	227,330.6	2,003,875.4	-1.69	227,365.5	2,003,872.9	0.88	227,362.9	2,003,873.1	0.52	35.0	32.4

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
Depth of closure and elevations of landward limit of beach change relative to PRVD02

Table J-23. Locations of maximum beach elevation change, ranges, and high and low elevations of envelope for SWMU 4 (southwest-facing).

Transect	Easting	Northing	Range	High	Low
S4-01	227,921.0	2,002,944.7	1.58	2.34	0.77
S4-02	227,885.4	2,002,999.0	0.65	1.60	0.95
S4-03	227,837.5	2,003,032.9	0.77	1.59	0.83
S4-04	227,794.0	2,003,040.6	0.55	-0.07	-0.61
S4-05	227,758.2	2,003,069.0	0.45	1.12	0.67
S4-06	227,694.6	2,003,125.5	0.55	0.58	0.03
S4-07	227,639.0	2,003,158.5	0.29	0.04	-0.25
S4-08	227,586.3	2,003,210.4	0.38	1.02	0.64
S4-09	227,516.5	2,003,294.6	0.75	1.58	0.83
S4-10	227,395.2	2,003,349.0	0.45	1.37	0.92
S4-11	227,331.6	2,003,374.0	0.72	1.65	0.93
S4-12	227,279.8	2,003,395.9	0.74	1.78	1.04
S4-13	227,203.3	2,003,420.3	1.03	0.86	-0.17

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
High and low elevations relative to PRVD02

Table J-24. Locations of maximum beach elevation change, ranges, and high and low elevations of envelope for SWMU 4 (west-facing).

Transect	Easting	Northing	Range	High	Low
S4-14	227,243.3	2,003,496.0	0.60	1.12	0.52
S4-15	227,268.3	2,003,541.5	0.78	0.76	-0.02
S4-16	227,353.7	2,003,653.1	0.61	1.20	0.58
S4-17	227,367.4	2,003,773.3	0.32	0.97	0.65
S4-18	227,363.6	2,003,873.0	0.43	0.88	0.45

All dimensions in m, coordinates in Universal Transverse Mercator (UTM) 20 N NAD83
High and low elevations relative to PRVD02

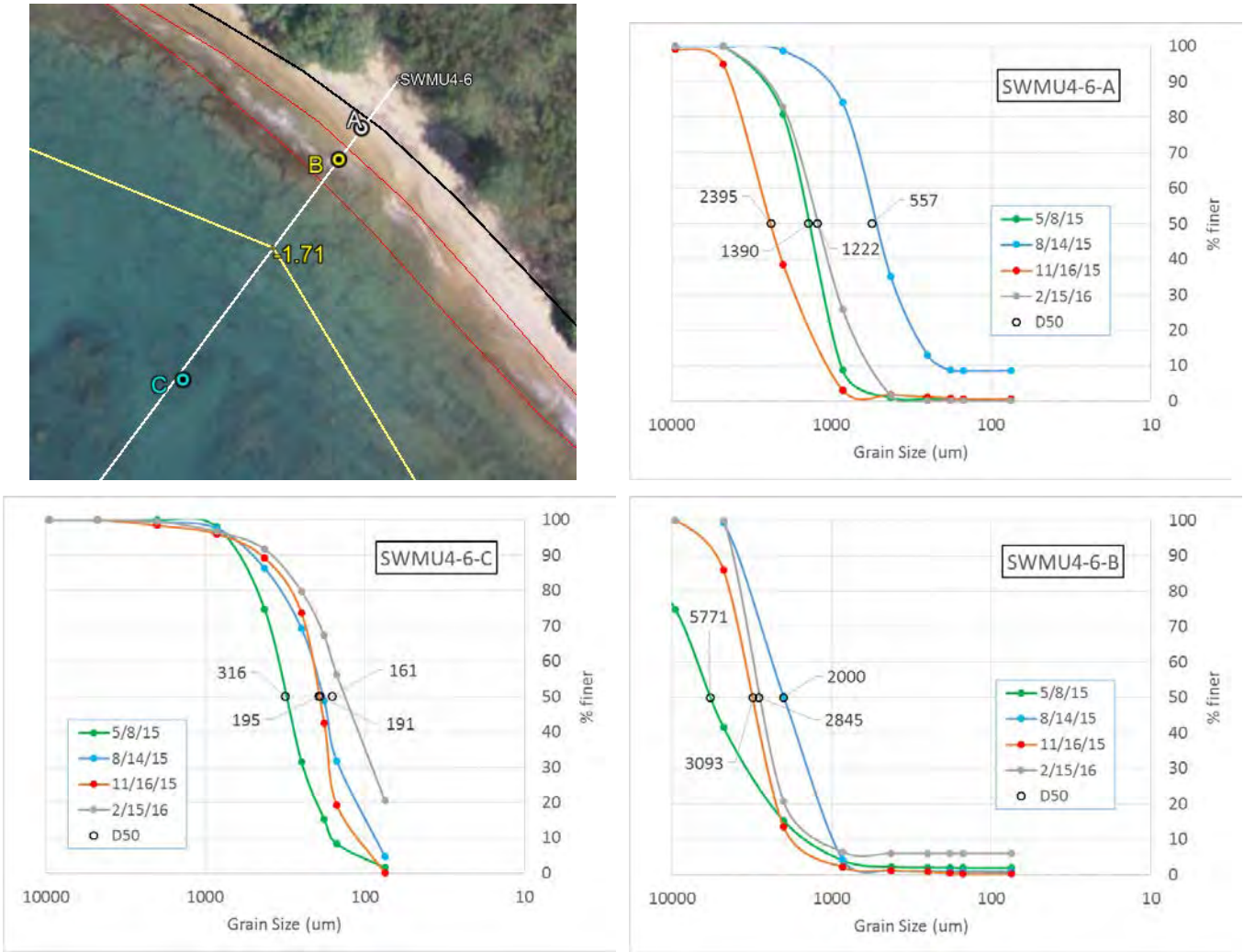

Figure J-178. Clockwise from top: approximate locations of sediment samples at SWMU 4 (south-facing), BDI landward limit of beach change, maximum landward and seaward shoreline positions, depth of closure; and distribution of grain size at backshore (A), shoreline (B) and nearshore (C) locations.

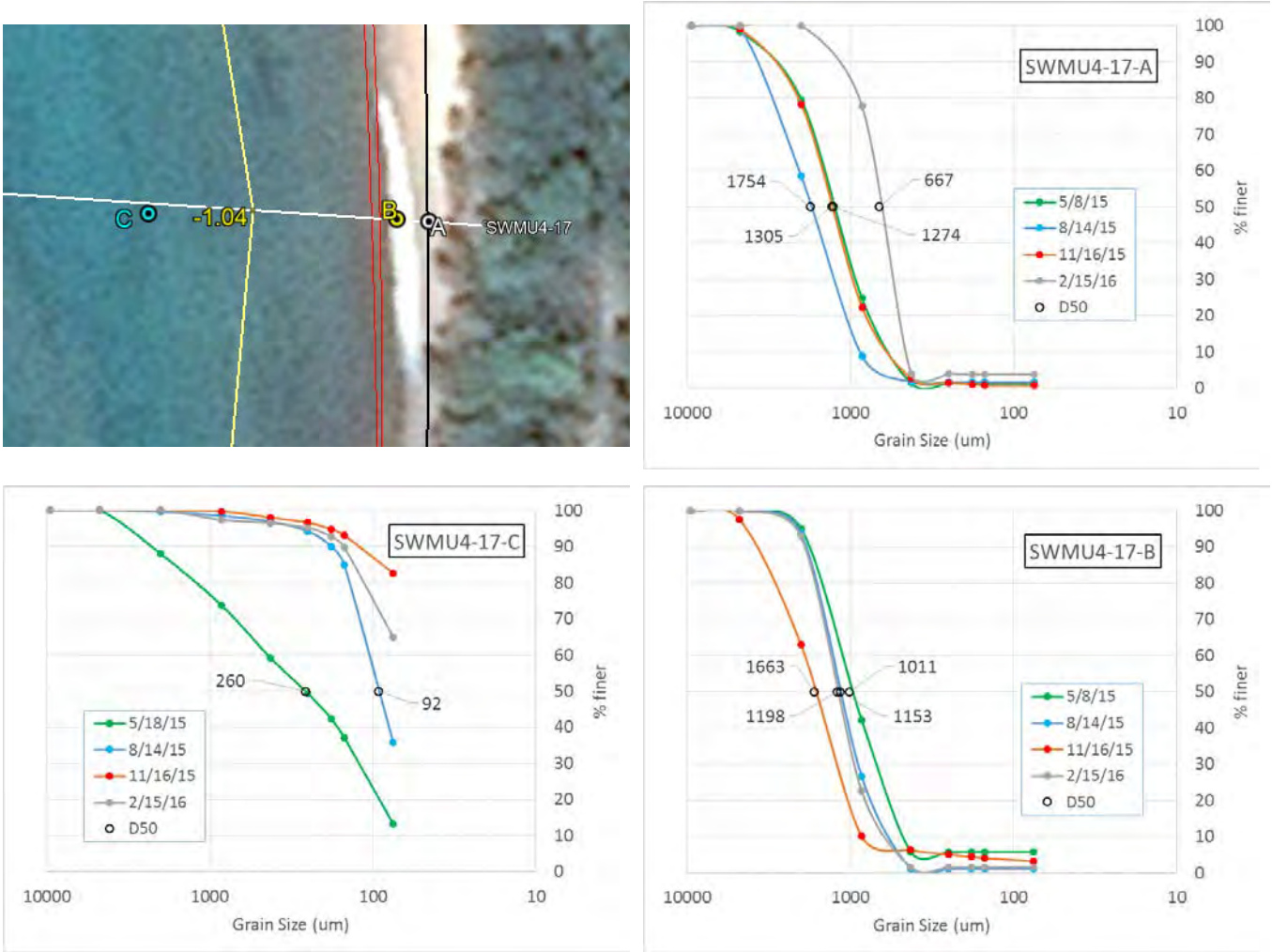

Figure J-179. Clockwise from top: approximate locations of sediment samples at SWMU 4 (west-facing), BDI landward limit of beach change, maximum landward and seaward shoreline positions, depth of closure; and distribution of grain size at backshore (A), shoreline (B) and nearshore (C) locations.

Appendix K
MEC Surrogate Surveys Results and Analysis

APPENDIX K

Munitions Surrogate Surveys Results and Analysis

1. Prediction of Depth of Burial

The formula by Demir et. al (2007) combined with the range of vertical bottom change measured at the Beach Dynamics Investigation (BDI) beaches, produced the best correlation between predicted and measured depths of burial. The depth of burial is defined as the distance between the bottom of the surrogate, at the location of its maximum diameter, and the average bottom in the vicinity of the surrogate. For perpendicular wave-induced flow on cylinders on sandy bottom, the formula by Demir et al. (2007) is given by:

$$B_d / D = 2\ \Theta^{0.8}$$

where B_d is the depth of burial, D is the diameter of the cylinder, and Θ is the Shields parameter. The Shields parameter is given by:

$$\Theta = 0.5\ f_w\ U_w^2 / \{ (S - 1)\ g\ D_{50} \}$$

where U_w is the maximum horizontal water particle velocity at the bottom, $S = \rho_s / \rho_w$ where ρs and ρ_w are the densities of the sediment and water, respectively, D_{50} in the mean grain diameter of the bottom sediment. The wave friction factor, f_w, is given by:

$$f_w = 0.3 \qquad \text{if } A / (2.5\ D_{50}) \leq 1.57$$

$$f_w = 0.00251 \exp \{ 5.21\ (A / 2.5 / D_{50})^{-0.19} \} \qquad \text{if } A / (2.5\ D_{50}) > 1.57$$

where A is the maximum water particle horizontal amplitude at the bottom.

For each surrogate, the depth of burial was predicted using:

- The typical (average) annual significant wave height (Hs) and peak wave period (Tp) at the location of the surrogate, derived from a wave hindcast for 2015
- The water depth at the location of the surrogate, determined by the inspection the beach profiles measured during the BDI
- The diameter of the bottom sediment (D50) of the nearshore sediment of the beach where the surrogate was deployed, obtained from sampling and grain size analyses performed during the BDI
- The range of bottom vertical change, determined by inspecting the history of beach profiles closest to the surrogate
- The formula by Demir et al. (2007)

Figure K-1 shows predicted versus measured depth of burial for surrogates on sandy bottom, at locations with and with no vertical beach bottom changes, where the assumed burial mechanism is wave-induced scour.

2. Potential of Munitions Burial and Mobility

The potential of the wave conditions present during the first year of the BDI (2015) to bury and move munitions and explosives of concern (MEC) at the surrogate locations was analyzed by comparing empirical estimates with measurements. At each surrogate location, water depths, sediment sizes, surrogate diameter and density were used with a wave hindcast for 2015 to derive hindcasts of enhanced bottom shear stress due to waves, and mobility parameter (MP) as defined by Friedrichs (2015). The year 2015 was a typical year with regards to metocean conditions in Vieques. However, it included Tropical Storm Erika which generated atypical changes on the south coast beaches. Consequently, the use of wave hindcasts for 2015 allowed to estimate the potential

burial and mobility of MEC in typical conditions at the BDI beaches, as well as in an atypical condition like Tropical Storm Erika on the south coast beaches.

The enhanced bottom shear stress due to waves accounts for the presence of a cylindrical object (e.g., MEC) on the bottom which affects the local hydrodynamic flow augmenting its velocity, generating turbulence, and increasing the shear stress which could potentially move sediment. When the enhanced bottom shear stress due to this interaction exceeds the critical shear stress of the sediment, scour of the bottom and MEC burial is expected to occur. This process has been described by several investigators including Inman et al. (2002), Voropayev et al. (2003), Cataño-Lopera et al. (2006), and Richardson et al. (2001), among others.

The enhanced bottom shear stress due to waves was calculated by simply increasing the corresponding undisturbed bottom shear stress by a factor of 2, as recommended by Hansen et al. (1991) and Demir et al. (2007). The stress increment factor of 2 applies to cylindrical objects perpendicular to the wave direction and on sandy bottoms, which are conditions different than those of the surrogates. However, some similarities exist, which allowed to assume that this would be a reasonable approach for the estimation of MEC self-burial. The undisturbed bottom shear stress due to waves was calculated as follows:

$$\tau = \tfrac{1}{2}\, \rho_w\, f_w\, U_w^2$$

where ρ_w is the density of the water, U_w is the maximum undisturbed bottom orbital velocity, and f_w is the wave friction coefficient calculated according to Swart (1974),

$$f_w = 0.3 \qquad \text{for } A/(2.5\, D_{50}) \leq 1.57$$

$$f_w = 0.00251 \exp\left[\, 5.21\, (A/(2.5\, D_{50})^{0.194}\, \right] \qquad \text{for } A/(2.5\, D_{50}) > 1.57$$

and A is the wave orbital amplitude at the bottom.

The average and maximum enhanced bottom shear stress due to waves at the location of each surrogate for the wave conditions of 2015 were computed from the corresponding hindcasts and compared to the critical shear stress of the bottom sediment (USGS, 2008), which varies with sediment size.

The mobility parameter, MP, was calculated according to Friedrichs (2015) as:

$$MP = U_w^2 / [\, (\rho_s / \rho_w - 1)\, D\, g\,]$$

where ρ_s is the density of the surrogate, D is the diameter of the surrogate, and g is the acceleration due to gravity. When the MP exceeds the critical MP, the surrogate is expected to move on the bottom. The approach developed by Friedrichs (2015) applies to cylindrical objects perpendicular to the wave direction and on sandy bottoms, which are conditions different than those of the surrogates. However, some similarities exist, which allowed to assume that Friedrichs (2015) would be a reasonable approach for the estimation of munitions mobility. The densities of the surrogates are listed in **Table K-1**.

Table K-1. Munitions Surrogate Volumes, Weights, and Densities

MEC Surrogate	Volume [a]		Weight [b]		Density
	(inch^3)	(m^3)	(lbs)	(kg)	(kg/m^3)
5-inch 38 Caliber Projectile	307.16	0.0050334	51.6	23.41	4,650
2.75-inch Rocket	359.33	0.0058884	15.2	6.89	1,171
MK 82 Bomb	4,880.35	0.0799746	530.0	226.80	3,006
MK 118 Submunition	20.14	0.0003300	2.0	3.18	2,749
81-mm Mortar	41.98	0.0006879	7.0	3.18	4,615
MK 76 Practice Bomb	135.82	0.0022256	23.0	10.43	4,687

a. from three-dimensional digital models developed for fabrication
b. from QC prior to deployment

inch^3 = cubic inch
kg = kilogram
lbs = pounds
m^3 = cubic meter
mm = millimeter

The average and maximum MPs at the location of each surrogate for the wave conditions of 2015 were computed from the corresponding hindcasts and compared with the critical MP derived by Friedrichs (2015). Because the critical MP depends on the ratio between surrogate (object) diameter (D) and depth of burial (B_d), a D/B_d ratio of 10 was assumed based on field observations. **Figure K-2** shows the regions of motion, and MP as a function of D/B_d according to Friedrichs (2015). For a $D/B_d = 10$ the critical MP is 0.39.

3. Wave Hindcast

The MIKE 21 Spectral Wave (SW) model (DHI, 2017) was used with wave measurements at the acoustic wave and current sensor (AWAC) locations to produce hindcasts of hourly Hs, T_p and mean wave direction (MWD) for 2015 along the former Vieques Naval Training Range (VNTR) coast, and particularly at the BDI beaches. **Figure K-3** shows the MIKE 21 SW model domain, depth contours (meter [m], PRVD02) and AWAC locations. The model north boundary was forced with waves measured at AWAC-N, the east boundary with waves measured at AWAC-E and the south boundary with AWAC-S measurements. **Figure K-4** shows the MIKE 21 SW wave hindcast model mesh.

Figure K-5 shows an example of Hs (m) contours and MWD at Bahia Salina del Sur, and Beaches 2, 3, and 4 at the peak of Tropical Storm Erika. Also at the peak of Tropical Storm Erika, **Figure K-6** shows Hs (m) contours and MWD at the east end of Vieques and Beaches 12 and 14, and **Figure K-7** at Beach 24 and vicinity. The effects of the local bathymetry and coastal features (e.g. refraction and diffraction) on wave height and direction are clearly shown.

4. Results and Analyses

The results and analyses presented in the following sections are based on observations and surveys performed during the BDI, measurements performed during the replacement of acoustic transmitters in September 2016 and during the recovery of the surrogates in July 2017, and the wave hindcast for 2015. Because 2015 was a typical year in Vieques with regards to metocean conditions, resulting depth of burial and mobility measurements and estimates can also be considered typical. Tropical Storm Erika on August 28, 2015, generated atypical changes on the south coast beaches and the burial and mobility parameters derived for that event could also be considered atypical, but not representative of an extreme event such as a hurricane.

Results and analyses are presented for:

- Live Impact Area (LIA) UXO 2 Beaches 2, 3, 4, 5, and 14
- North Eastern Maneuver Area (EMA) and Surface Impact Area (SIA) UXO 7 Beaches 22 and 24
- South SIA UXO 8 Beaches 1 and 19

For each beach, the following is presented:

- Aerial views of surrogate deployment locations and depth of closure, surrogates at the same locations were not deployed bundled but a few meters apart from each to prevent interference
- Displacements of surrogates
- Measured and predicted depth of burial
- Summary of depth of burial and mobility analyses
  - bottom and wave conditions
  - potential of burial and mobility
  - measured and predicted depth of burial, and estimated time to fully buried

The time of the munitions surrogates to be fully buried was estimated from visual observations made from the survey boat during the surrogate surveys performed approximately once a month. Therefore, the estimates are, at best, within 30 days of the time when the fully buried event took place. An exception to this would be the times to fully buried of 100 to 115 days (between 3 to 4 months) because these were reported during the first survey which took place approximately 4 months after the deployment of the surrogates.

5. References

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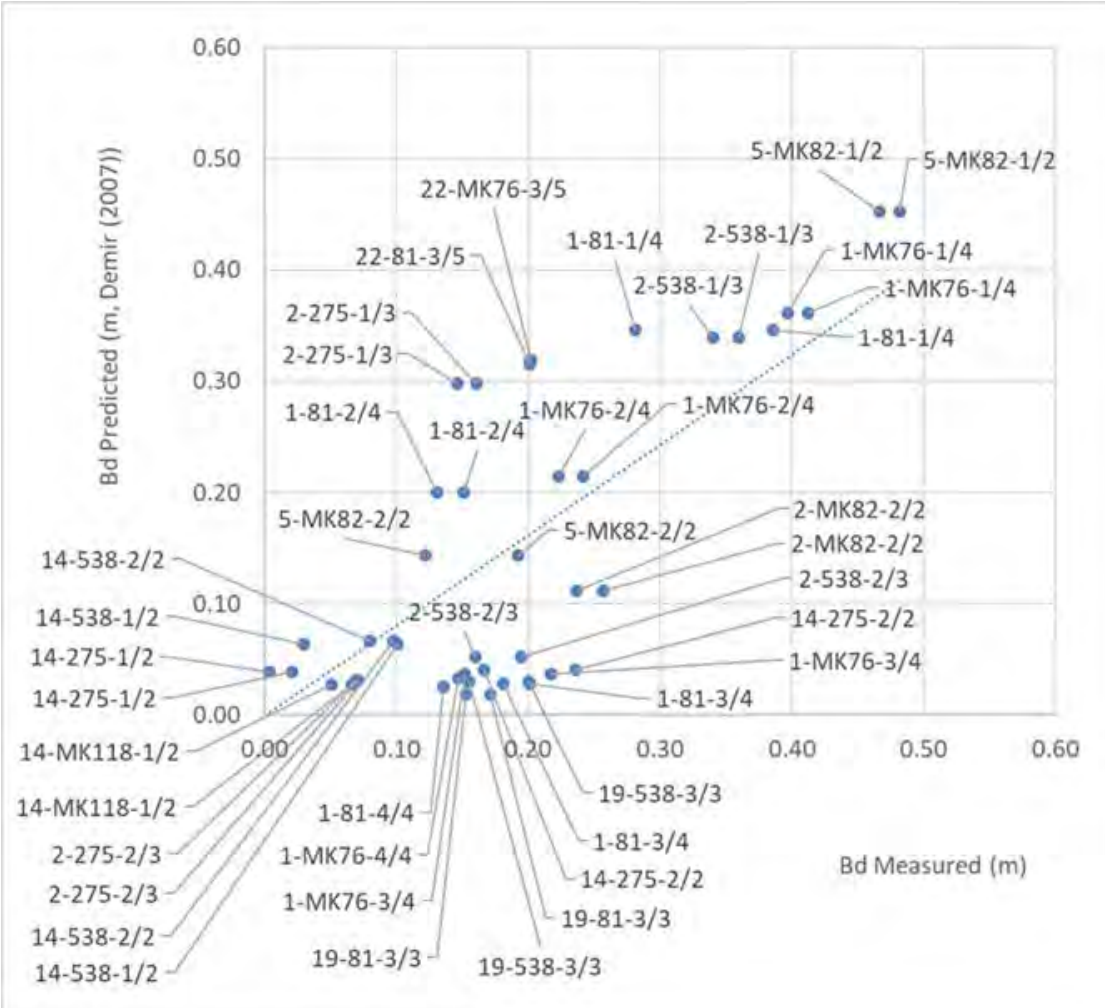

Figure K-1. Predicted versus measured depth of burial and best fit line (R^2 = 0.57).

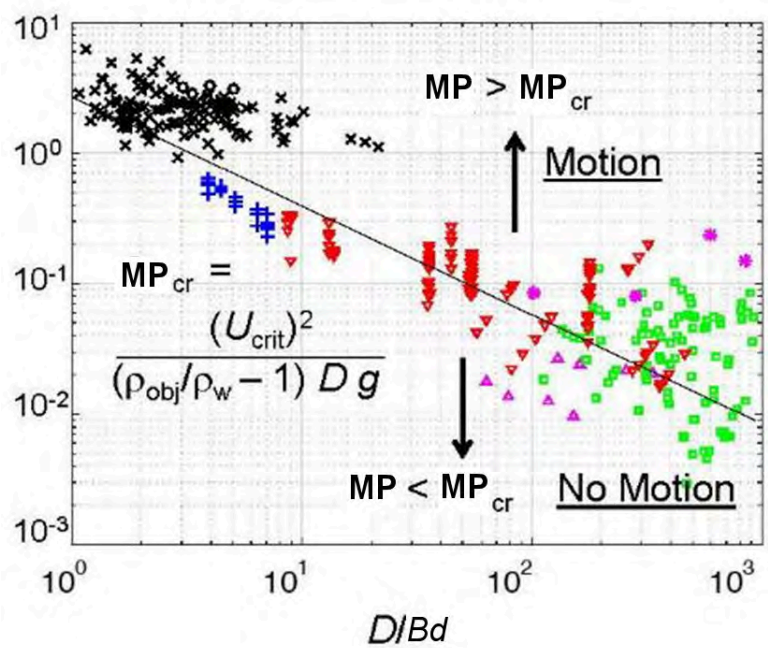

Figure K-2. MP versus D/B_d and regions of motion (adapted from Friedrichs, 2015).

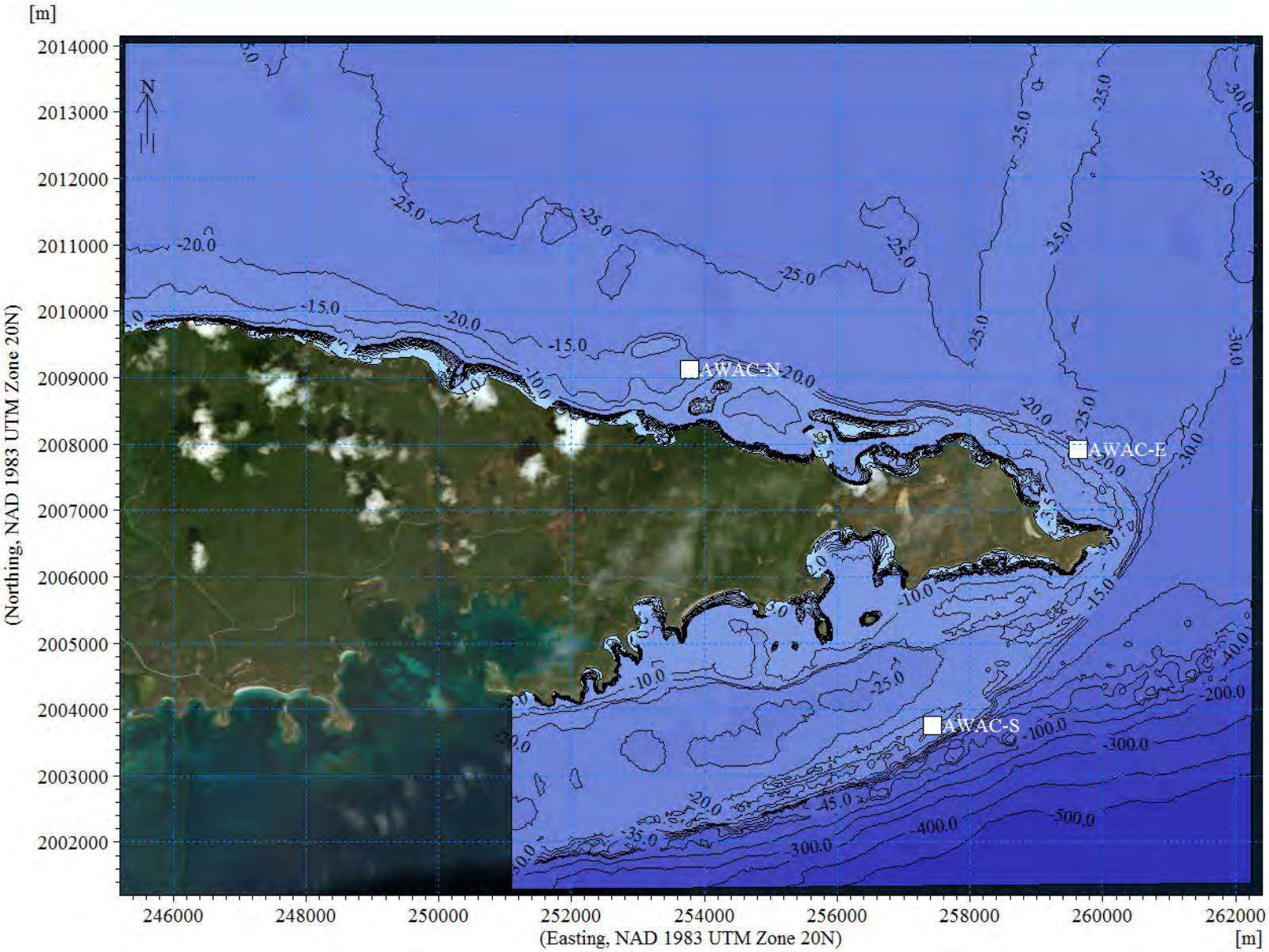

Figure K-3. MIKE 21 SW wave hindcast model domain, depth contours (m, PRVD02) and AWAC locations.

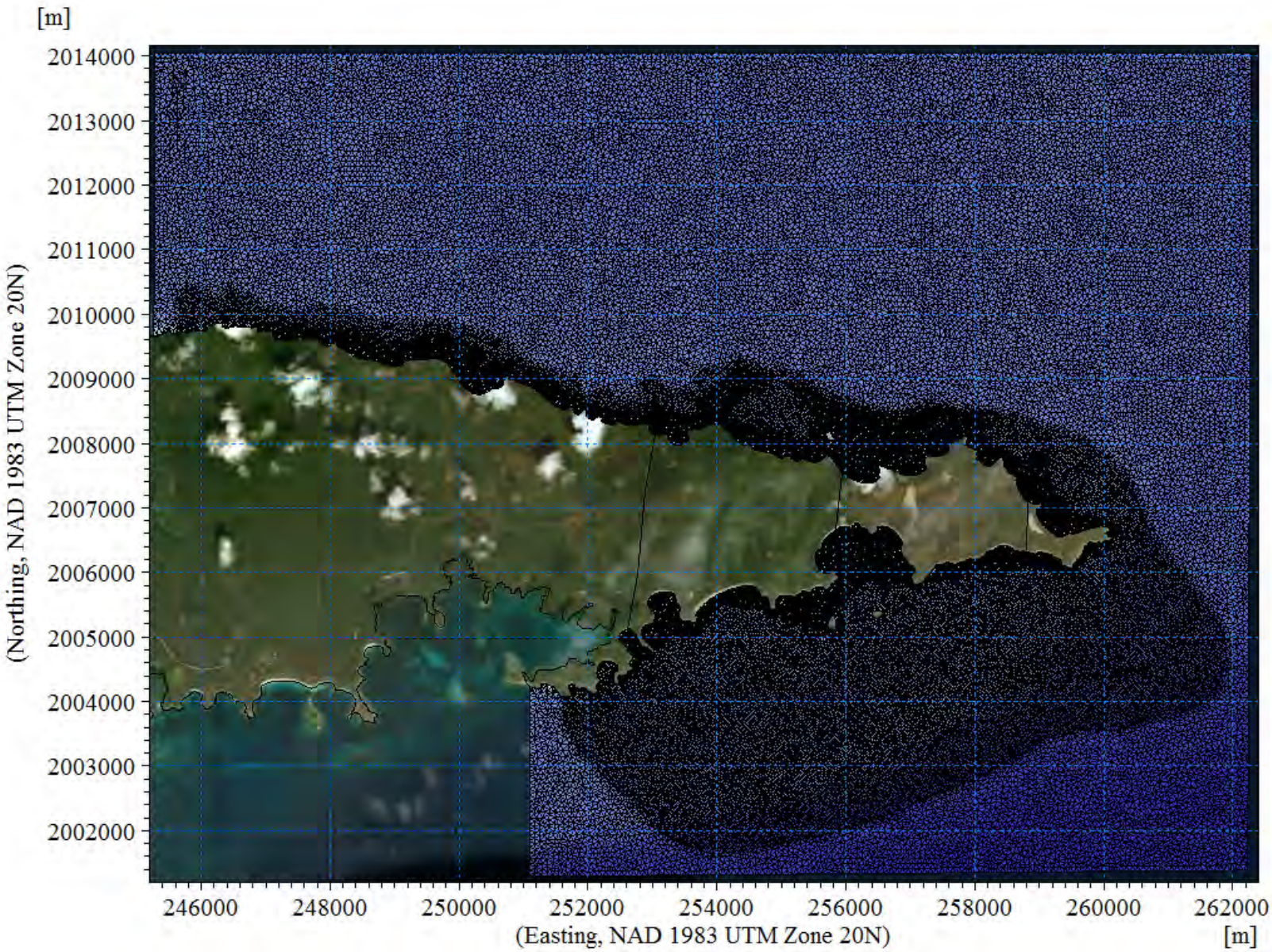

Figure K-4. MIKE 21 SW wave hindcast model mesh.

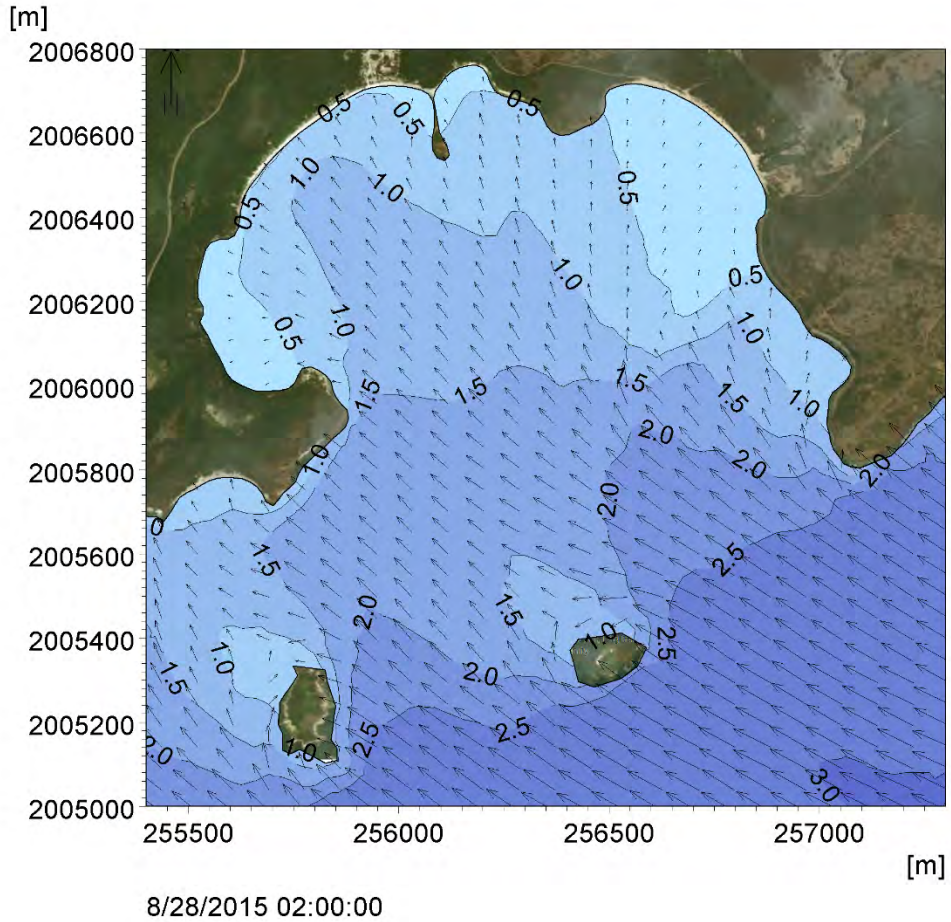

Figure K-5. Hs contours (m) and MWD at Bahia Salina del Sur and Beach 2, 3 and 4 at the peak of Tropical Storm Erika.

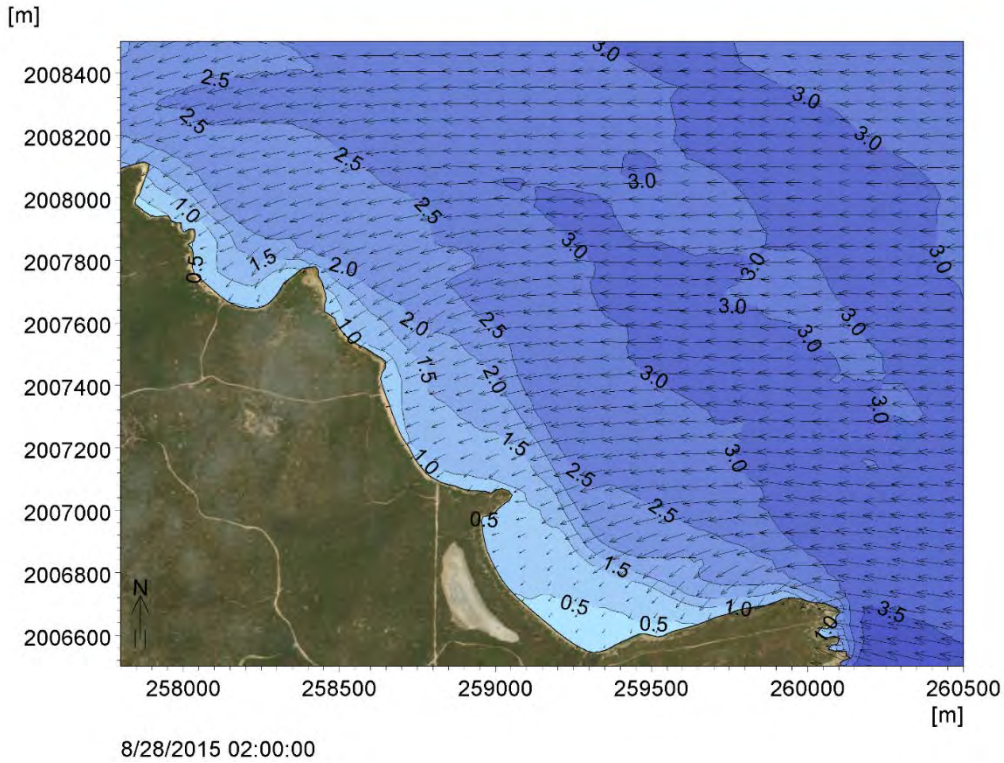

Figure K-6. Hs contours (m) and MWD at the east end of Vieques, Beach 12 and 14 at the peak of Tropical Storm Erika.

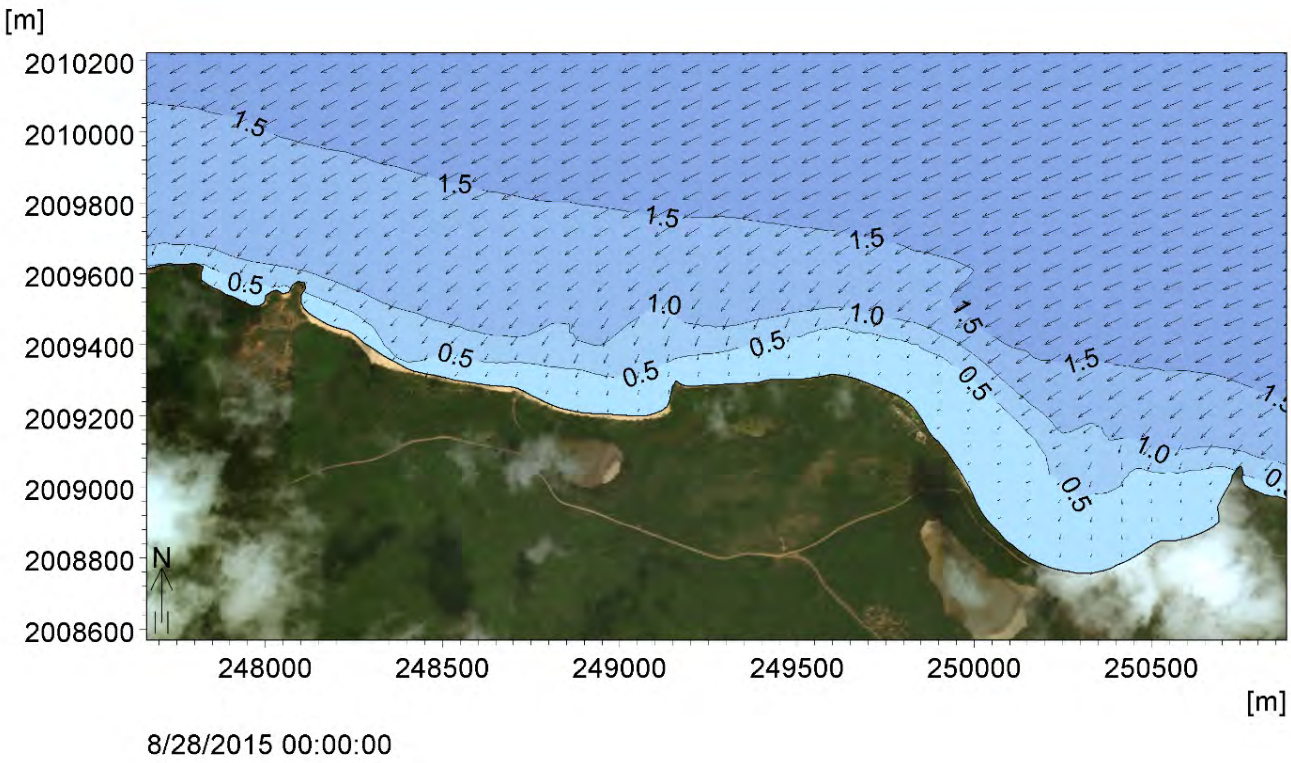

Figure K-7. Hs contours (m) and MWD at Beach 24 and vicinity at the peak of Tropical Storm Erika.

LIA UXO 2
Beach 2

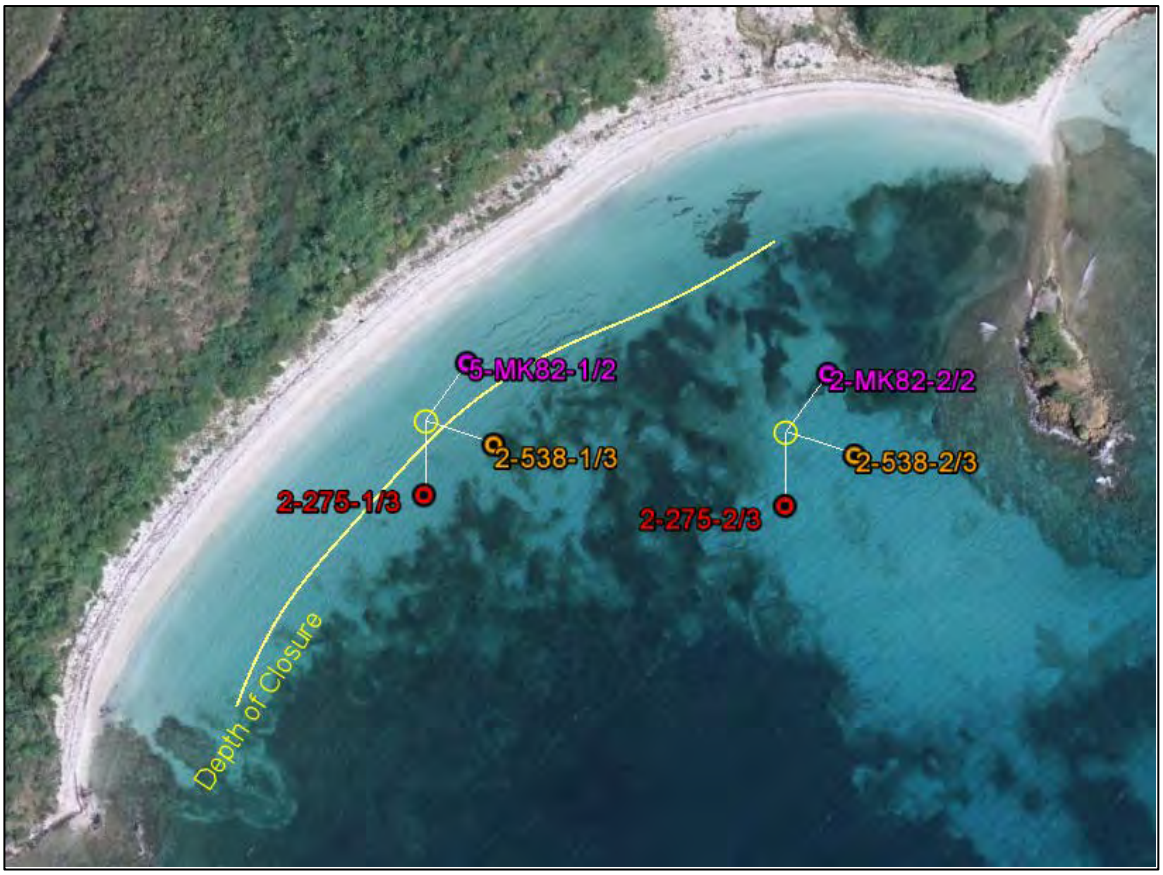

Figure K-8. Surrogate deployment locations in the nearshore, and depth of closure at Beach 2 (5-MK82-1/2 deployed instead of 2-MK82-1/2; 2-275-3/3 and 2-538-3/3 located offshore not included for clarity).

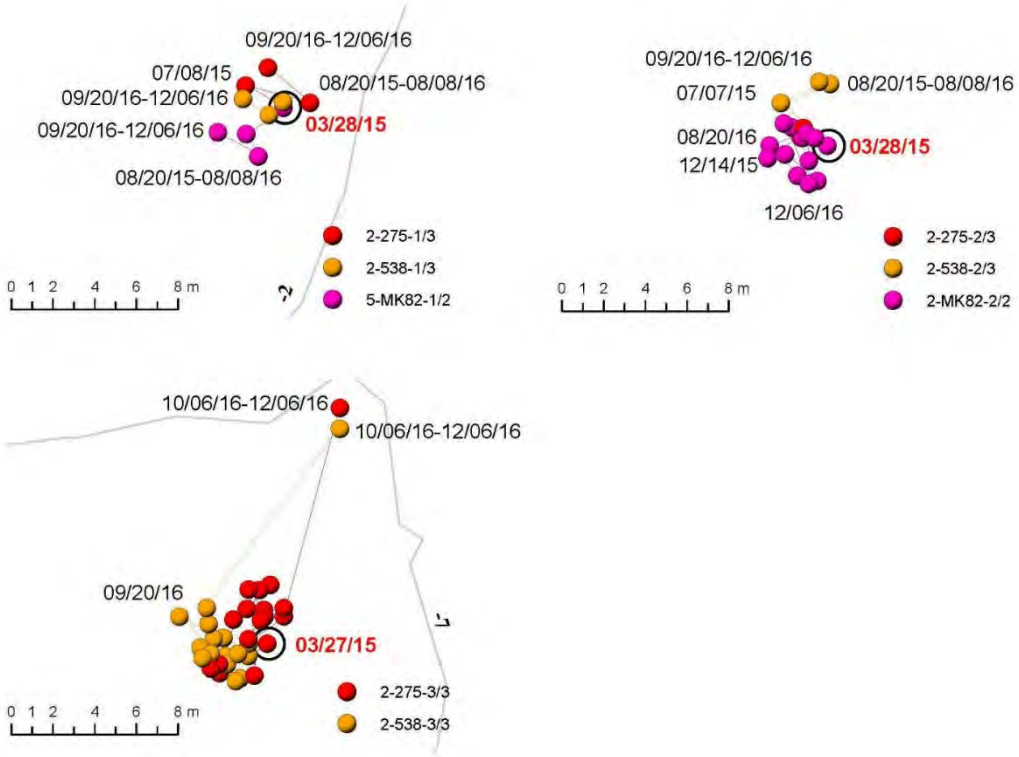

Figure K-9. Displacement of surrogates at Beach 2 (circled = date and location of deployment).

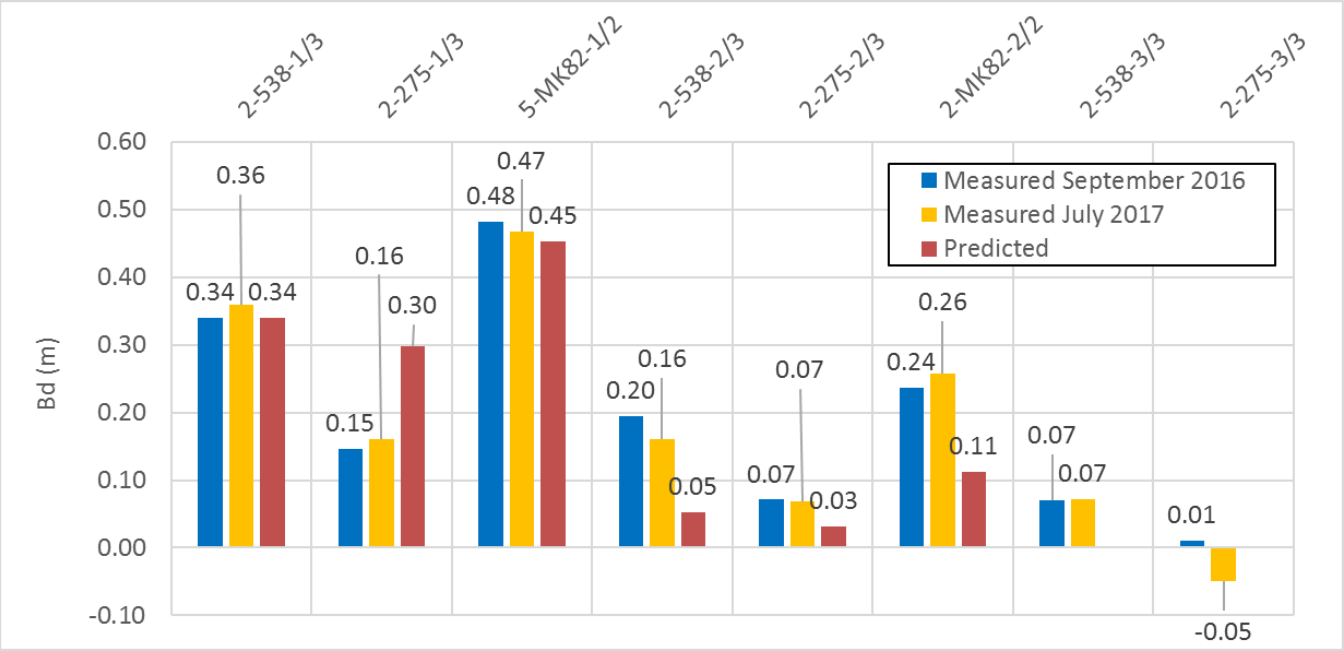

Figure K-10. Measured and predicted depths of burial of surrogates at Beach 2 (no prediction where bottom is seagrass).

Table K-1. Summary of Burial and Mobility Analyses for Surrogates at Beach 2

ID	Bottom				Potential of MEC Burial and Mobility								Depth of Burial (B_d)				
					Typical				Maximum [b]				Measured		Predicted	B_d/D [c]	Time [d]
	Depth	Range [a]	Type	D_{50}	H_s	T_p	τ	MP	H_s	T_p	τ	MP	Sep-2016	Jul-2017			
2-538-1/3								0.02				0.16	0.34	0.36	0.34	2.69	179
2-275-1/3	2.00	0.24	S	0.12	0.33	4.4	**1.09**	**0.96**	0.86	5.0	**5.86**	**6.74**	0.15	0.16	0.30	2.02	179
5-MK82-1/2								0.02				0.14	0.48	0.47	0.45	1.71	179
2-538-2/3	3.22							0.01				0.10	0.20	0.16	0.05	1.37	179
2-275-2/3	3.22	0.00	S	0.12	0.29	4.7	**0.50**	**0.39**	0.89	5.6	**3.65**	**4.07**	0.07	0.07	0.03	0.92	179
2-MK82-2/2	3.31							0.01				0.08	0.24	0.26	0.11	0.89	200
2-538-3/3	7.13	0.00	SGrs	-	0.52	5.4	-	-	1.66	6.5	-	-	0.07	0.07	-	0.55	-
2-275-3/3	7.08												0.01	-0.05		-0.25	-

a. range of bottom change based on BDI surveys at surrogate location
b. Tropical Storm Erika on August 28, 2015
c. based on average of measured B_d
d. days from deployment to fully buried Dimensions in m, D_{50} in mm, T_p in seconds, τ in N/m^2

MEC surrogate diameters: 5-inch 38 Caliber Projectile = 0.130 m, 2.75-inch Rocket = 0.076 m, MK 82 Bomb = 0.277 m

bold = exceeds critical, critical τ = 0.11 N/m^2 for D_{50}, critical MP = 0.39 for D/B_d = 10 (Friedrichs, 2015)
- no depth of burial prediction, and burial and mobility analysis where bottom is seagrass

S = sand, SGrs = seagrass

τ = enhanced (due to surrogate/bottom interaction) wave-induced shear stress for 2015 conditions (assumed 2 x wave-induced shear stress)

- <u>2-538-1/3, 2-275-1/3 and 5-MK82-1/2; and 2-538-2/3, 2-275-2/3 and 2-MK82-2/2</u>

  a) The surrogates were located on a sandy bottom, in relatively shallow water and in an area of relatively low waves,

     i) 2-538-1/3, 2-275-1/3 and 5-MK82-1/2, landward of the depth of closure where the bottom exhibited changes, and

     ii) 2-538-2/3, 2-275-2/3 and 2-MK82-2/2, seaward of the depth of closure where the bottom exhibited no changes.

  b) For all surrogates, the enhanced shear stresses (due to typical waves and surrogate/bottom interaction) exceeded the bottom sediment critical shear stress suggesting that typical conditions were conducive to the self-burial of these surrogates.

  c) For:

     i) 2-538-1/3, 5-MK82-1/2, 2-538-2/3 and 2-MK82-2/2, the average MPs did not exceed the critical MP suggesting that typical conditions were not conducive to the mobility of these surrogates.

     ii) 2-275-1/3 and 2-275-2/3, the average MPs exceeded the critical MP suggesting that typical conditions were conducive to the mobility of these surrogates. However, the large fins in their tails may have prevented/limited their mobility.

  d) For all surrogates, the surveys (tracking) showed displacements in no dominant direction, and of the same magnitude as the expected positioning resolution of the vessel used for the surveys.

  e) The considerations above, the range of bottom vertical change measured at the location of the surrogates and depth of burial measurements support the notion that:

     i) 2-538-1/3, 2-275-1/3 and 5-MK82-1/2 did not move and self-buried to a shallow depth initially, and deeper afterwards due to beach-wide bottom changes. Furthermore, the very fine sediment at the surrogate location may have facilitated deep burial by bottom fluidization.

     ii) 2-538-2/3, 2-275-2/3 and 2-MK82-2/2 did not move and self-buried to a shallow depth. Despite the very fine sediment at the surrogate location, local conditions may have limited deep burial by bottom fluidization.

  f) For all surrogates, the maximum MPs was reached during Tropical Storm Erika.

     i) For 2-538-1/3, 5-MK82-1/2, 2-538-2/3 and 2-MK82-2/2, the maximum MPs would have not exceeded the critical MP. No displacements were observed because the surrogates were likely self-buried already, and buried further by a berm formed in the nearshore by sediment transported seaward by the storm.

     ii) For 2-275-1/3 and 2-275-2/3, the maximum MPs would have exceeded the critical MP. However, the large fins in their tails could have prevented/limited their mobility.

- <u>2-538-3/3 and 2-275-3/3</u>

  a) The surrogates were located on a sandy bottom covered with seagrass, in relatively deep water and in an area of relatively high waves, seaward of the depth of closure where the bottom exhibited no changes.

  b) The seagrass should have prevented/limited the self-burial and mobility of these surrogates.

  c) The surrogate surveys (tracking) showed displacements in no dominant direction and of the same magnitude as the expected positioning resolution of the vessel used for the surveys. A relatively large landward displacement is noted between September 20 and October 6, 2016, which could be attributed to waves generated by Hurricane Matthew on September 29, 2016.

d) The considerations above, and depth of burial measurements support the notion that these surrogates did not move and remained minimally or not buried, but could have moved during the passage of Hurricane Matthew.

LIA UXO 2
Beach 3

Figure K-11. Surrogate deployment locations and depth of closure at Beach 3.

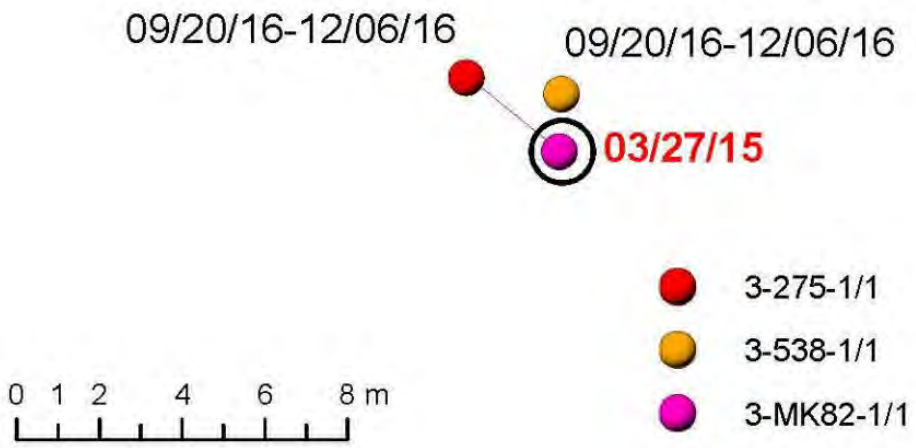

Figure K-12. Displacement of surrogates at Beach 3 (circled = date and location of deployment).

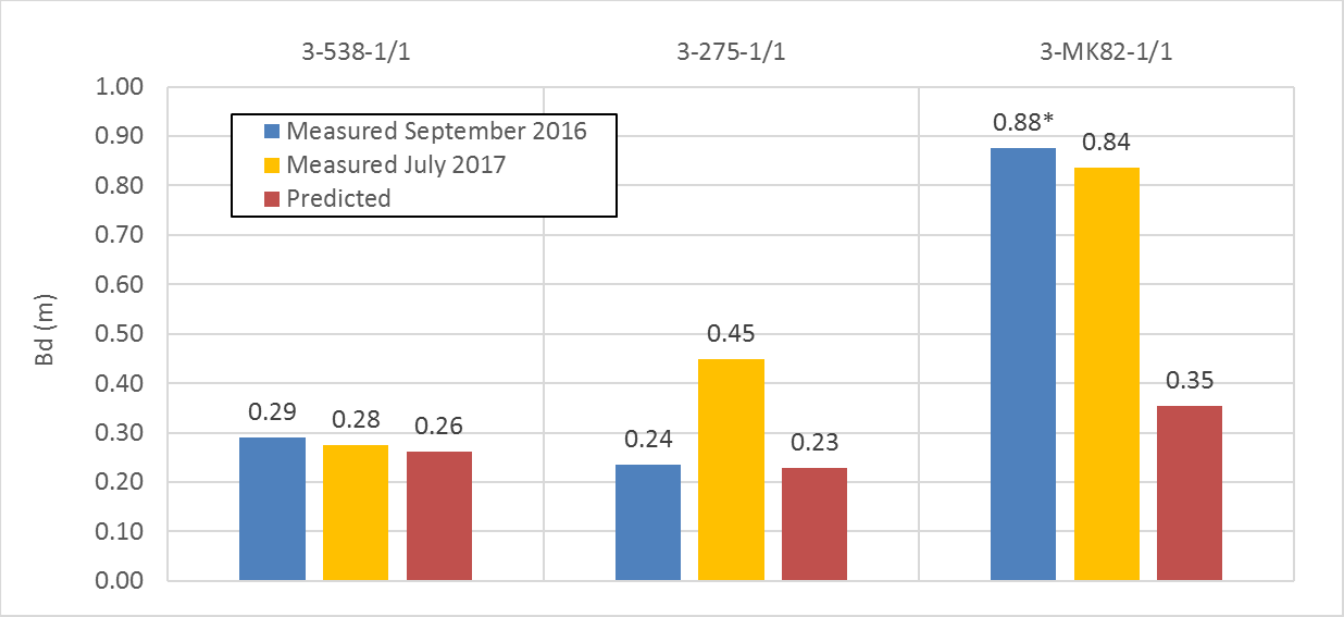

Figure K-13. Measured and predicted depths of burial of surrogates at Beach 3 (* estimated by divers).

Table K-2. Summary of Burial and Mobility Analyses for Surrogates at Beach 3

ID	Bottom				Potential of MEC Burial and Mobility								Depth of Burial (B_d)				
					Typical				Maximum [b]				Measured		Predicted	B_d/D [c]	Time [d]
	Depth	Range [a]	Type	D_{50}	H_s	T_p	τ	MP	H_s	T_p	τ	MP	Sep-2016	Jul-2017			
3-538-1/1								0.02				0.10	0.29	0.28	0.26	2.17	104
3-275-1/1	1.37	0.18	S	0.11	0.22	3.9	**0.81**	**0.67**	0.55	4.4	**3.87**	**4.13**	0.24	0.45	0.23	4.50	104
3-MK82-1/1								0.01				0.08	0.88*	0.84	0.35	3.09	104

a. range of bottom change based on BDI surveys at surrogate location
b. Tropical Storm Erika on August 28, 2015
c. based on average of measured Bd
d. days from deployment to fully buried Dimensions in m, D_{50} in mm, T_p in seconds, τ in N/m^2

MEC surrogate diameters: 5-inch 38 Caliber Projectile = 0.130 m, 2.75-inch Rocket = 0.076 m, MK 82 Bomb = 0.277 m

bold = exceeds critical, critical τ = 0.11 N/m^2 for D_{50}, critical MP = 0.39 for D/Bd = 10 (Friedrichs, 2015)
* estimated by divers

S = sand

τ = enhanced (due to surrogate/bottom interaction) wave-induced shear stress for 2015 conditions (assumed 2 x wave-induced shear stress)

- <u>3-538-1/1, 3-275-1/1 and 3-MK82-1/1</u>

  a) The surrogates were located on a sandy bottom, in relatively shallow water and in an area of relatively low waves, landward of the depth of closure where the bottom exhibited changes.

  b) The enhanced shear stresses (due to typical waves and surrogate/bottom interaction) exceeded the bottom sediment critical shear stress suggesting that typical conditions were conducive to the self-burial of these surrogates.

  c) For:

     i) 3-538-1/1 and 3-MK82-1/1, the average MPs did not exceed the critical MP suggesting that typical conditions were not conducive to the mobility of these surrogates.

     ii) 3-275-1/1, the average MP exceeded the critical MP suggesting that typical conditions were conducive to the mobility of this surrogate. However, the large fins in its tail may have prevented/limited its mobility.

  d) The surrogate surveys (tracking) showed minor displacements in the landward direction, but these were of the same magnitude as the expected positioning resolution of the vessel used for the surveys.

  e) The considerations above, the range of bottom vertical change measured at the location of the surrogates and depth of burial measurements support the notion that these surrogates did not move, but self-buried to a shallow depth initially, and deeper afterwards due to beach-wide bottom changes. In addition, the relatively deep depths of burial of the surrogates could have resulted from the very fine bottom sediment which could have facilitated deep burial by bottom fluidization.

  f) For:

     i) 3-538-1/1 and 3-MK82-1/1, the maximum MPs would have been reached during Tropical Storm Erika, but would have not exceeded the critical MP. No displacements were observed because the surrogates were likely buried already at the time of the storm.

     ii) 3-275-1/1, the maximum MP would have been reached during Tropical Storm Erika and would have exceeded the critical MP. However, the large fins in its tail could have prevented/limited its mobility.

LIA UXO 2
Beach 4

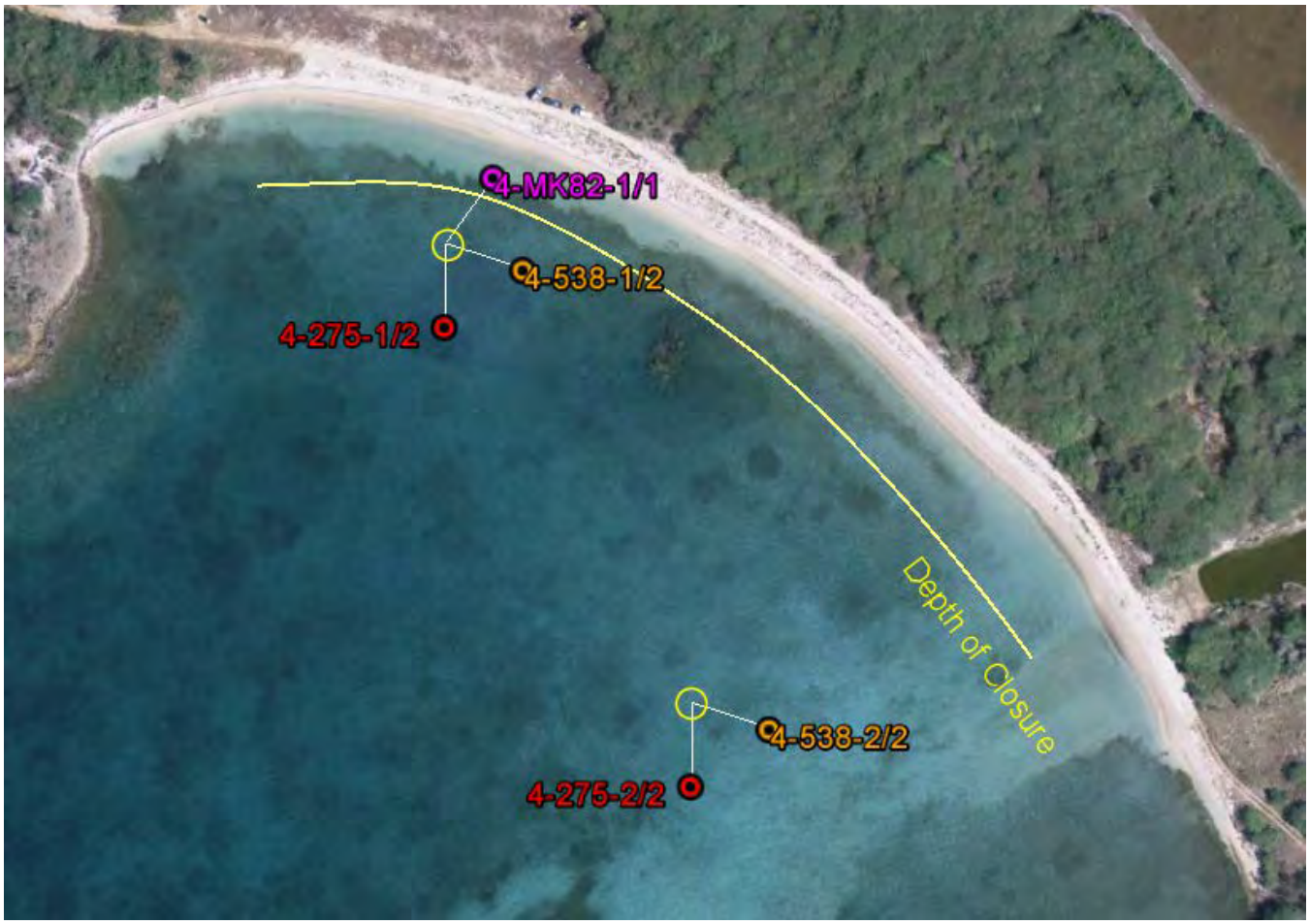

Figure K-14. Surrogate deployment locations and depth of closure at Beach 4.

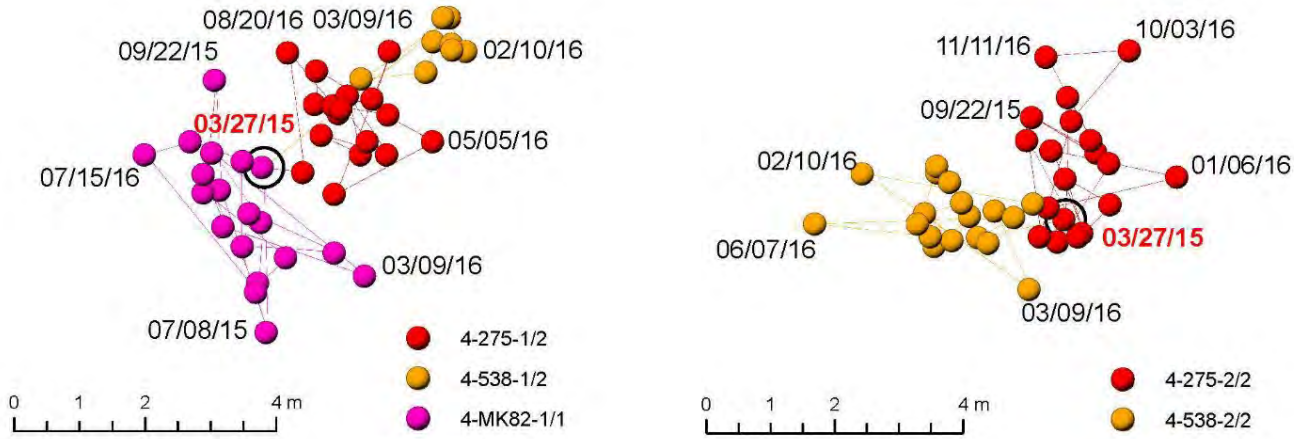

Figure K-15. Displacement of surrogates at Beach 4 (circled = date and location of deployment).

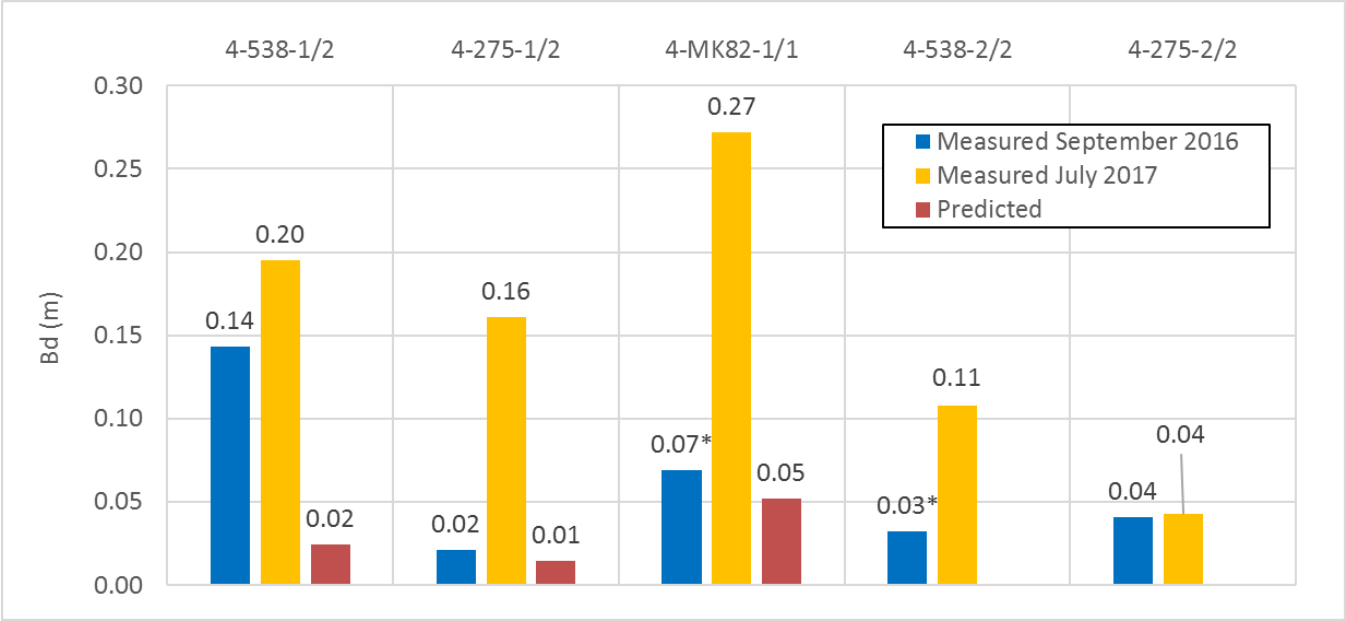

Figure K-16. Measured depths of burial of surrogates at Beach 4 (no prediction where bottom is seagrass).

Table K-3. Summary of Burial and Mobility Analyses for Surrogates at Beach 4

ID	Bottom				Potential of MEC Burial and Mobility								Depth of Burial (B_d)				
					Typical				Maximum [b]				Measured		Predicted	B_d/D [c]	Time [d]
	Depth	Range [a]	Type	D_{50}	H_s	T_p	τ	MP	H_s	T_p	τ	MP	Sep-2016	Jul-2017			
4-538-1/2	2.19							0.00				0.02	0.14	0.20	0.02	1.30	285
4-275-1/2	2.26	0.00	S	0.14	0.15	3.6	**0.21**	0.12	0.39	4.5	**1.24**	**1.04**	0.02	0.16	0.01	1.20	595
4-MK82-1/1	2.34							0.00				0.02	0.07*	0.27	0.05	0.62	-
4-538-2/2	2.13	0.00	SGrs	-	0.18	3.2	-	-	0.42	4.2	-	-	0.03*	0.11	-	0.54	-
4-275-2/2	2.08												0.04	0.04		0.55	-

a. range of bottom change based on BDI surveys at surrogate location
b. Tropical Storm Erika on August 28, 2015
c. based on average of measured B_d
d. days from deployment to fully buried

Dimensions in m, D_{50} in mm, T_p in seconds, τ in N/m^2
MEC surrogate diameters, 5-inch 38 Caliber Projectile = 0.130 m, 2.75-inch Rocket = 0.076 m, MK 82 Bomb = 0.277 m
- no depth of burial prediction, and burial and mobility analysis where bottom is seagrass
* estimated from underwater photos

bold = exceeds critical, critical τ = 0.15 N/m^2 for D_{50}, critical MP = 0.39 for D/B_d = 10 (Friedrichs, 2015)

S = sand, SGrs = seagrass

τ = enhanced (due to surrogate/bottom interaction) wave-induced shear stress for 2015 conditions (assumed 2 x wave-induced shear stress)

- 4-538-1/2, 4-275-1/2 and 4-MK82-1/1
  a) The surrogates were located on a sandy bottom, in relatively shallow water and in an area of relatively low waves, seaward of the depth of closure where the bottom exhibited no changes.
  b) The enhanced shear stresses (due to typical waves and surrogate/bottom interaction) exceeded the bottom sediment critical shear stress suggesting that typical conditions were conducive to the self-burial of these surrogates.
  c) For all surrogates, the average MPs did not exceed the critical MP suggesting that typical conditions were not conducive to the mobility of these surrogates.
  d) The surrogate surveys (tracking) showed displacements in no dominant direction, and of the same magnitude as the expected positioning resolution of the vessel used for the surveys.
  e) The considerations above, and depth of burial measurements support the notion that these surrogates did not move and remained minimally or not buried.
  f) For:
     i) 4-538-1/2 and 4-MK82-1/1, the maximum MPs were reached during Tropical Storm Erika, but did not exceed the critical MP.
     ii) 4-275-1/2, the maximum MP was reached during Tropical Storm Erika and exceeded the critical MP. However, the large fins in its tail could have prevented/limited its mobility.
- 4-538-2/2 and 4-275-2/2
  a) The surrogates were located on a sandy bottom covered with seagrass, in relatively shallow water and in an area of relatively low waves, seaward of the depth of closure where the bottom exhibited no changes.
  b) The seagrass should have prevented/limited the self-burial and mobility of these surrogates.
  c) The surrogate surveys (tracking) showed displacements with no dominant direction, and of the same magnitude as the expected positioning resolution of the vessel used for the surveys.
  d) The considerations above, and depth of burial measurements support the notion that these surrogates did not move and remained minimally or not buried.

LIA UXO 2
Beach 5

Figure K-17. Surrogate deployment locations and depth of closure at Beach 5 (14-MK82-1/1 deployed instead of 5-MK82-1/2, and 2-MK82-1/2 instead of 5-MK82-2/2).

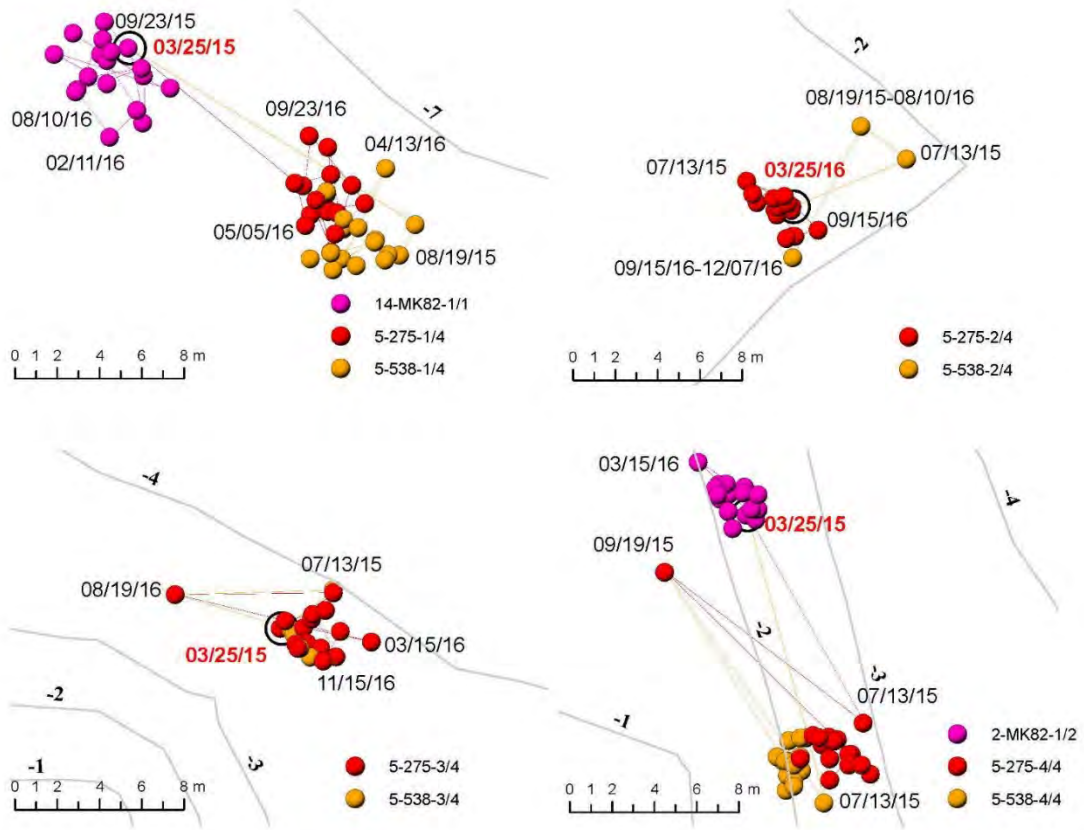

Figure K-18. Displacement of surrogates at Beach 5 (circled = date and location of deployment).

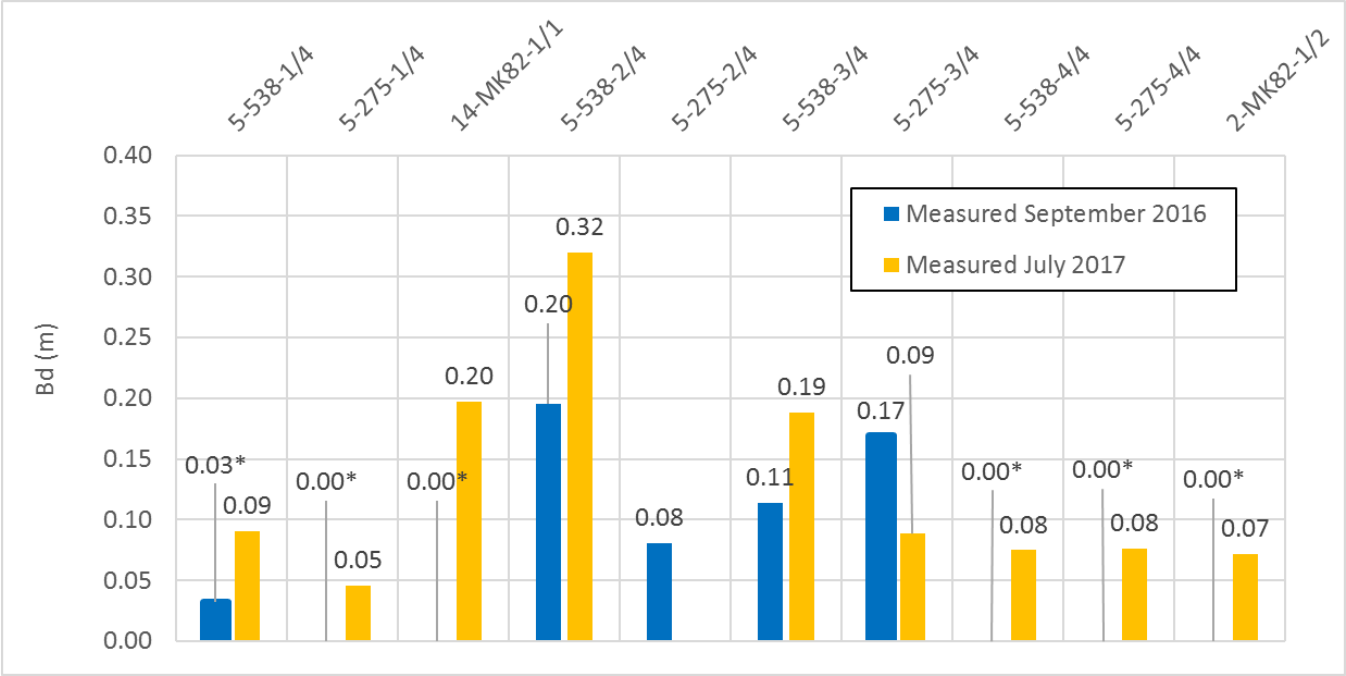

Figure K-19. Measured depths of burial of surrogates at Beach 5 (no prediction where bottom is seagrass, * estimated from underwater photos).

Table K-4. Summary of Burial and Mobility Analyses for Surrogates at Beach 5

ID	Bottom				Potential of MEC Burial and Mobility								Depth of Burial (B_d)				
					Typical				Maximum [b]				Measured		Predicted	B_d/D [c]	Time [d]
	Depth	Range [a]	Type	D_{50}	H_s	T_p	τ	MP	H_s	T_p	τ	MP	Sep-2016	Jul-2017			
5-538-1/4	7.06												0.03*	0.09		0.48	-
5-275-1/4	7.13	0.00	SGrs	-	0.30	3.6	-	-	0.42	2.8	-	-	0.00*	0.05	-	0.30	-
14-MK82-1/1	7.14												0.00*	0.20		0.36	-
5-538-2/4	2.44	0.00	SGrs	-	0.12	3.0	-	-	0.22	4.2	-	-	0.20	0.32	-	1.98	182
5-275-2/4	2.46												0.08	x		1.07	-
5-538-3/4	4.05	0.00	SGrs	-	0.20	3.5	-	-	0.33	4.1	-	-	0.11	0.19	-	1.16	260
5-275-3/4	4.14												0.17	0.09		1.70	323
5-538-4/4	2.64												0.00*	0.08		0.29	-
5-275-4/4	2.93	0.00	SGrs	-	0.23	3.2	-	-	0.30	2.7	-	-	0.00*	0.08	-	0.50	-
2-MK82-1/2	3.40												0.00*	0.07		0.13	-

a. range of bottom change based on BDI surveys at surrogate location
b. winter 2015
c. based on average of measured B_d
d. days from deployment to fully buried

Dimensions in m, D_{50} in mm, T_p in seconds, τ in N/m^2
MEC surrogate diameters, 5-inch 38 Caliber Projectile = 0.130 m, 2.75-inch Rocket = 0.076 m, MK 82 Bomb = 0.277 m
* estimated from underwater photos
- no depth of burial prediction, and burial and mobility analysis where bottom is seagrass
x = removed by intruder

SGrs = seagrass

τ = enhanced (due to surrogate/bottom interaction) wave-induced shear stress for 2015 conditions (assumed 2 x wave-induced shear stress)

- 5-538-1/4, 5-275-1/4 and 14-MK82-1/1
  a) The surrogates were located on a sandy bottom covered with seagrass, in relatively deep water and in an area of relatively low waves, seaward of the depth of closure where the bottom exhibited no changes.
  b) The seagrass should have prevented/limited the self-burial and mobility of these surrogates.
  c) The surrogate surveys (tracking) showed displacements with no dominant direction, and of the same magnitude as the expected positioning resolution of the vessel used for the surveys. However, after deployment, 5-538-1/4 and 5-275-1/4 exhibited similar and relatively large displacements to the southeast, but these did not correspond with the occurrence of a storm.
  d) The considerations above, and depth of burial measurements support the notion that these surrogates did not move and remained minimally or not buried.
- 5-538-2/4 and 5-275-2/4; 5-538-3/4 and 5-275-3/4; and 5-538-4/4, 5-275-4/4 and 2-MK82-1/2
  a) The surrogates were located on a sandy bottom covered with seagrass, in relatively shallow water and in an area of relatively low waves, seaward of the depth of closure where the bottom exhibited no changes.
  b) The seagrass should have prevented/limited the self-burial and mobility of these surrogates.
  c) The surrogate surveys (tracking) showed displacements with no dominant direction, and of the same magnitude as the expected positioning resolution of the vessel used for the surveys. However, after deployment, 5-538-4/4 and 5-275-4/4 exhibited similar and relatively large displacements in the longshore direction, but these did not correspond to the occurrence of a storm. The beach dynamics analysis showed that the western end of the beach, were these surrogates were deployed, is shaped by easterly wind waves generated within the bay, and the offshore waves that refract around Yallis Island. Currents induced by these waves may have moved these surrogates.
  d) The considerations above, and depth of burial measurements support the notion that only 5-538-4/4 and 5-275-4/4 moved, and that all other surrogates remained minimally or not buried.

LIA UXO 2
Beach 14

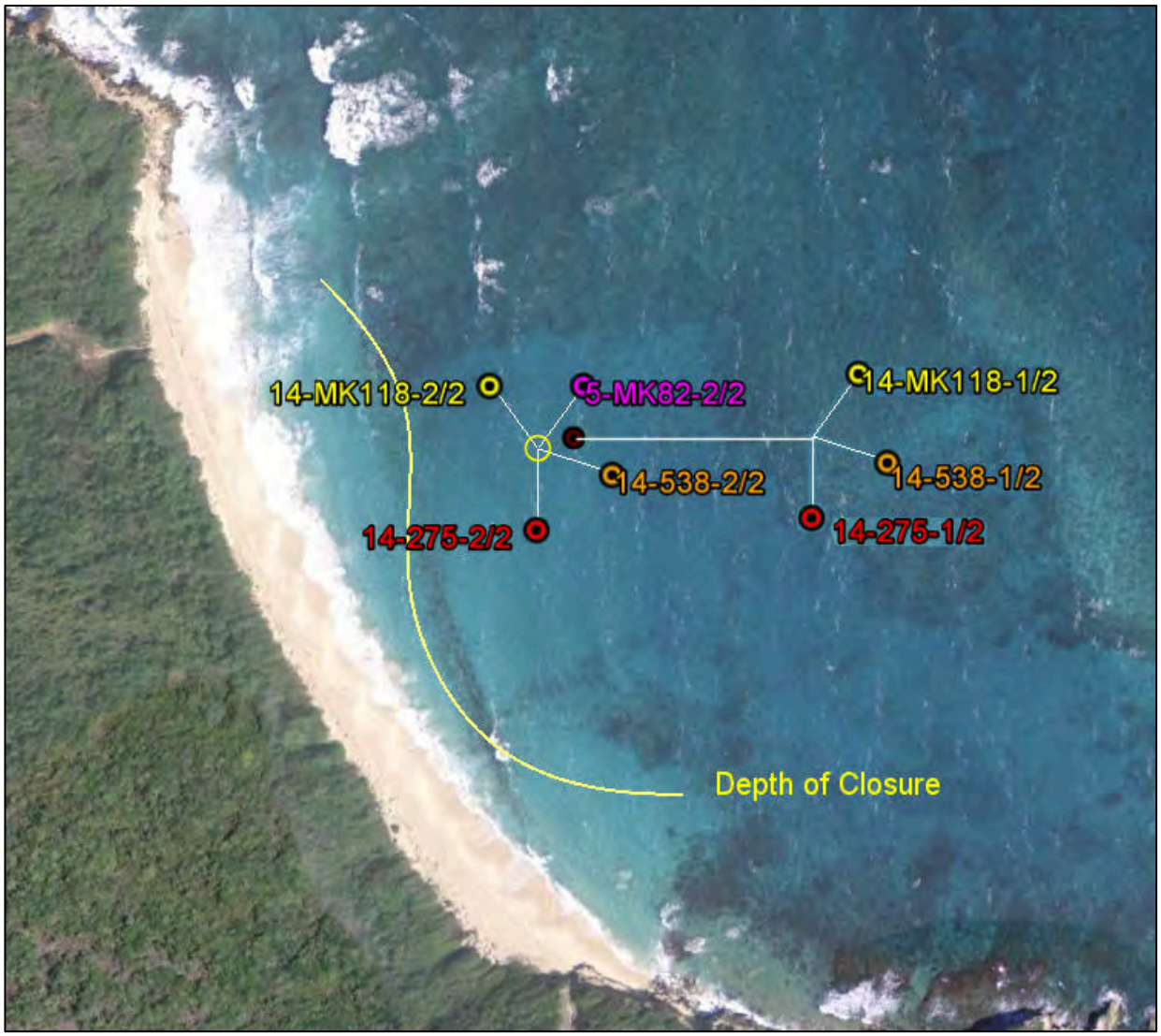

Figure K-20. Surrogate deployment locations and depth of closure at Beach 14 (5-MK82-2/2 deployed instead of 14-MK82-1/1).

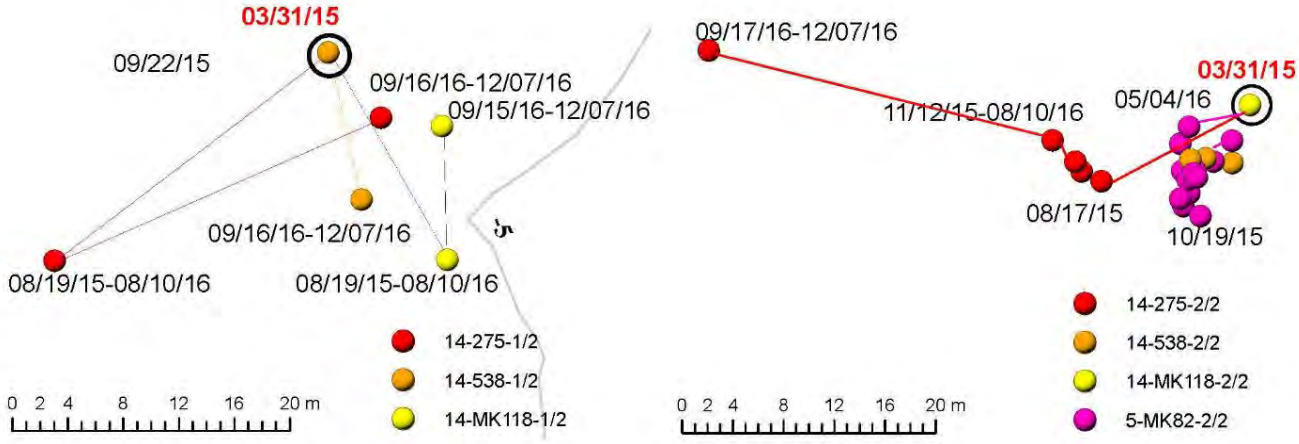

Figure K-21. Displacement of surrogates at Beach 14 (circled = date and location of deployment).

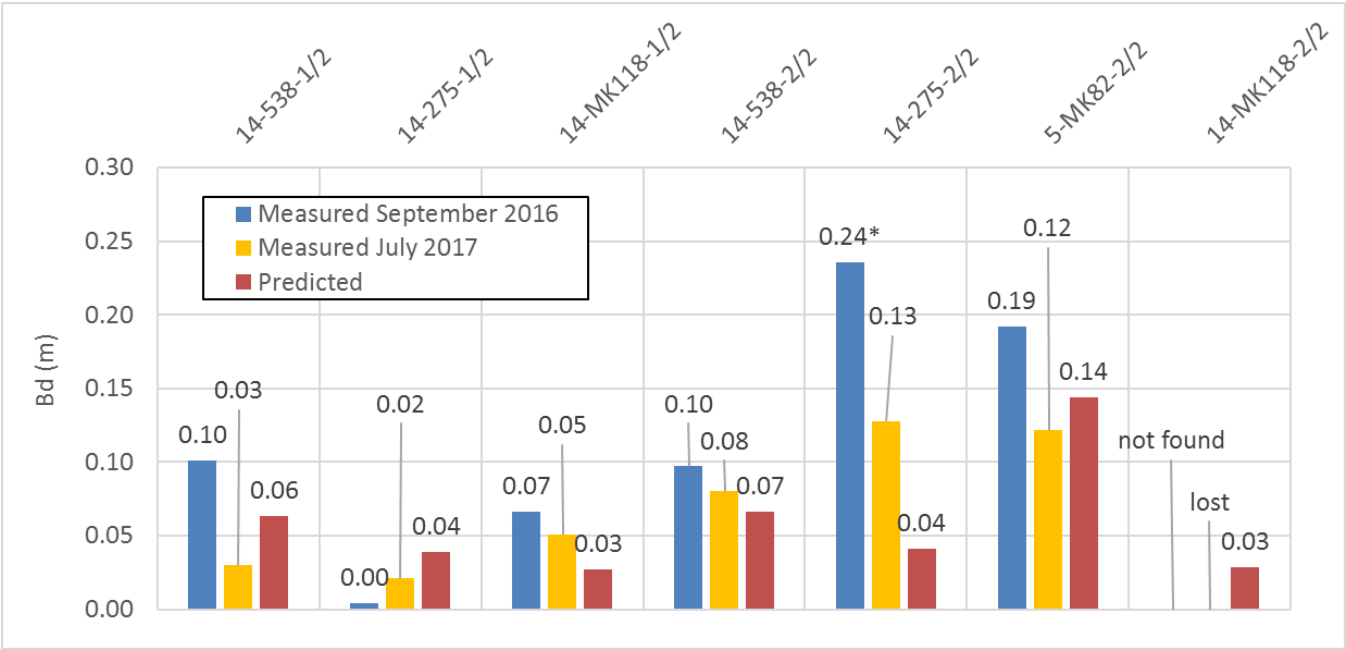

Figure K-22. Measured and predicted depths of burial of surrogates at Beach 14 (* estimated from underwater photos).

Table K-5. Summary of Burial and Mobility Analyses for Surrogates at Beach 14

ID	Bottom				Potential of MEC Burial and Mobility								Depth of Burial (B_d)				
					Typical				Maximum [b]				Measured		Predicted	B_d/D [c]	Time [d]
	Depth	Range [a]	Type	D_{50}	H_s	T_p	τ	MP	H_s	T_p	τ	MP	Sep-2016	Jul-2017			
14-538-1/2	5.07							0.05				0.22	0.10	0.03	0.06	0.50	-
14-275-1/2	4.87	0.00	S	0.59	0.86	5.4	**3.15**	**2.04**	1.51	9.1	**9.88**	**9.18**	0.00	0.02	0.04	0.16	-
14-MK118-1/2	5.14							0.23				**1.05**	0.07	0.05	0.03	1.04	115
14-538-2/2	4.86							0.05				0.22	0.10*	0.08	0.07	0.68	-
14-275-2/2	4.61	0.00	S	0.59	0.86	5.4	**3.15**	**2.04**	1.51	9.1	**9.88**	**9.18**	0.24	0.13	0.04	2.64	254
5-MK82-2/2	4.79							0.04				0.19	0.19	0.12	0.14	0.57	-
14-MK118-2/2	4.83							0.23				**1.05**	not found	lost	0.03	-	71

a. range of bottom change based on BDI surveys at surrogate location
b. winter 2015
c. based on average of measured B_d
d. days from deployment to fully buried Dimensions in m, D_{50} in mm, T_p in seconds, τ in N/m^2

MEC surrogate diameters, 5-inch 38 Caliber Projectile = 0.130 m, 2.75-inch Rocket = 0.076 m, MK 118 Submunition = 0.056 m, MK 82 Bomb = 0.277 m
* estimated from underwater photos

bold = exceeds critical, critical τ = 0.30 N/m^2 for D_{50}, critical MP = 0.39 for D/B_d = 10 (Friedrichs, 2015)

S = sand

τ = enhanced (due to surrogate/bottom interaction) wave-induced shear stress for 2015 conditions (assumed 2 x wave-induced shear stress)

- <u>14-538-1/2, 14-275-1/2 and 14-MK118-1/2; and 14-538-2/2, 14-275-2/2, 5-MK82-2/2 and 14-MK118-1/2</u>

  a) The surrogates were located on a sandy bottom, in an area of relatively high waves, and seaward of the depth of closure where the bottom exhibited no changes.

  a) The enhanced shear stresses (due to typical waves and surrogate/bottom interaction) exceeded the bottom sediment critical shear stress suggesting that typical conditions were conducive to the self-burial of these surrogates.

  b) For 14-275-1/2 and 14-275-2/2 the average MPs exceeded the critical MP suggesting that typical conditions were conducive to the mobility of these surrogates. For all others, the average MPs did not exceed the critical MP suggesting that typical conditions were not conducive to the mobility of these surrogates.

  c) The surveys (tracking) showed:

     i) For 14-538-1/2, 14-275-1/2 and 14-MK118-1/2, relatively large displacements in cross-shore and longshore directions, which exceeded the magnitude of the expected positioning resolution of the vessel used for the surveys. Surrogate 14-275-1/2 exhibited the largest displacements, despite the large fins in its tail which could have prevented/limited its mobility.

     ii) For 14-538-2/2, 14-275-2/2, 5-MK82-2/2 and 14-MK118-2/2, displacements with no dominant direction, and of the same magnitude as the expected positioning resolution of the vessel used for the surveys; except for 14-275-2/2 which exhibited large displacements, despite the large fins in its tail which could have prevented/limited its mobility.

  d) The considerations above, and depth of burial measurements support the notion that:

     i) 14-538-1/2, 14-275-1/2 and 14-MK118-1/2: moved initially, and self-buried to a shallow depth afterwards. Surrogate 14-275-1/2 was minimally buried.

     ii) 14-538-2/2, 14-275-2/2, 5-MK82-2/2 and 14-MK118-2/2: except 14-275-2/2, these surrogates did not move and self-buried to a shallow depth. Surrogate 14-275-2/2 was buried in the order of 3 diameters and significantly more than 14-275-1/2 which remained on the bottom. The difference could be attributed to a different orientation and proximity to a rock outcrop that could have altered the local hydrodynamics. Surrogate 14-MK118-2/2 was lost.

  e) For all surrogates, the maximum MPs occurred in the winter (February 2015).

     i) For the 275s and MK118s surrogates, the maximum MPs exceeded the critical MP suggesting that typical winter conditions would be conducive to the mobility of these surrogates.

     ii) For the 538s and the MK82, the maximum MPs did not exceed the critical MP suggesting that typical winter conditions were not be conducive to the mobility of these surrogates.

North EMA and SIA UXO 7
Beach 22

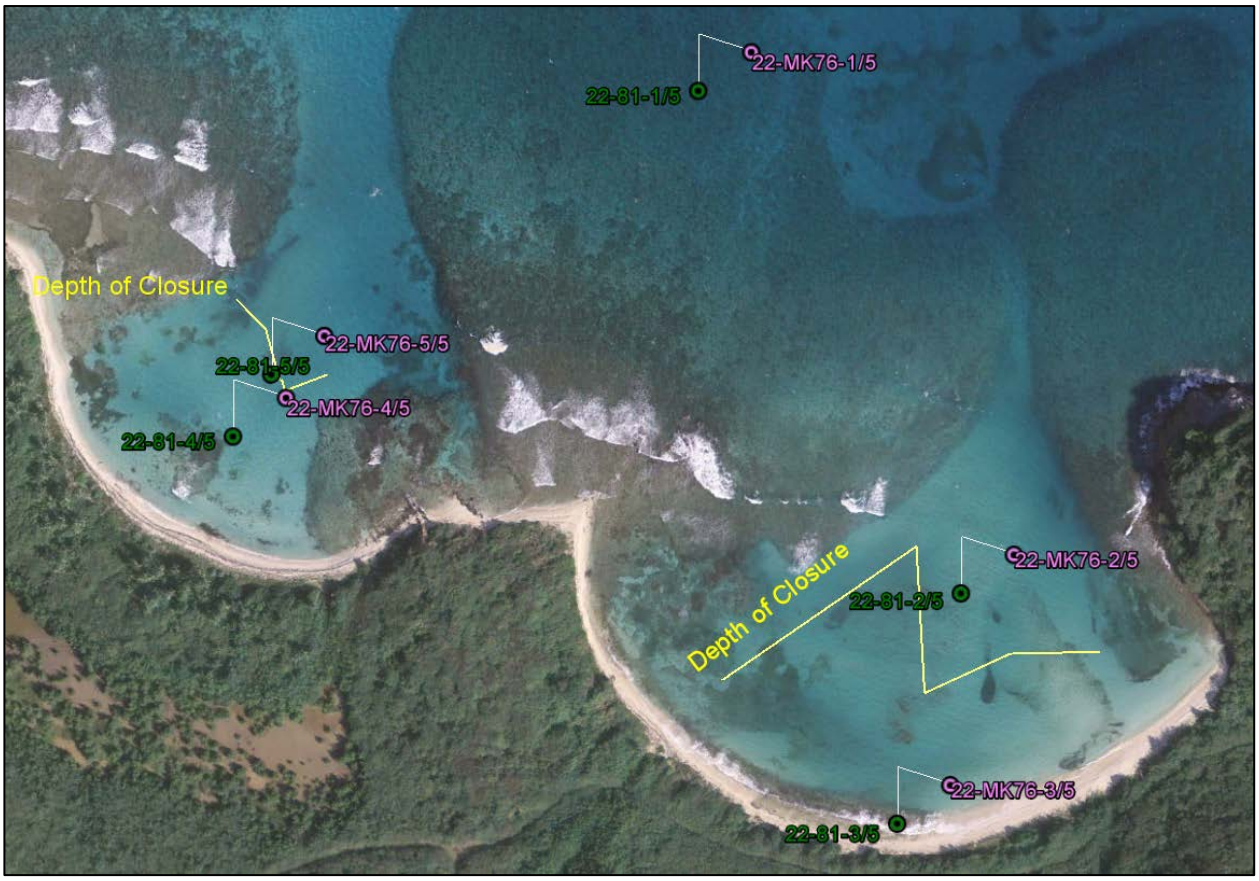

Figure K-23. Surrogate deployment locations and depth of closure at Beach 22.

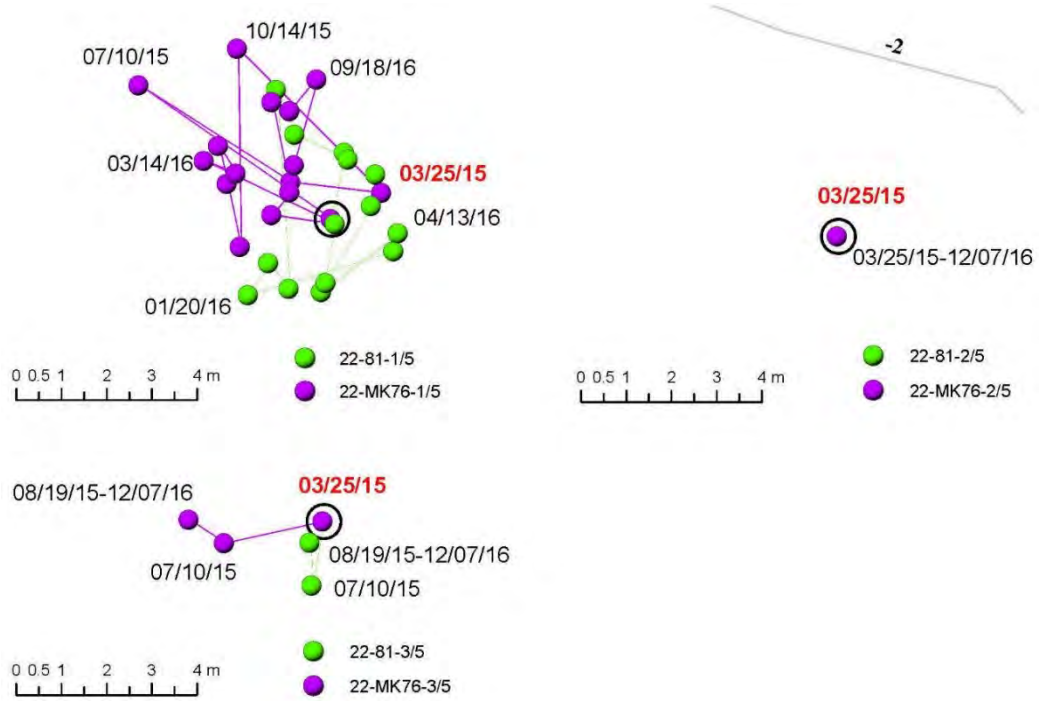

Figure K-24. Displacement of surrogates at Beach 22 (east, circled = date and location of deployment).

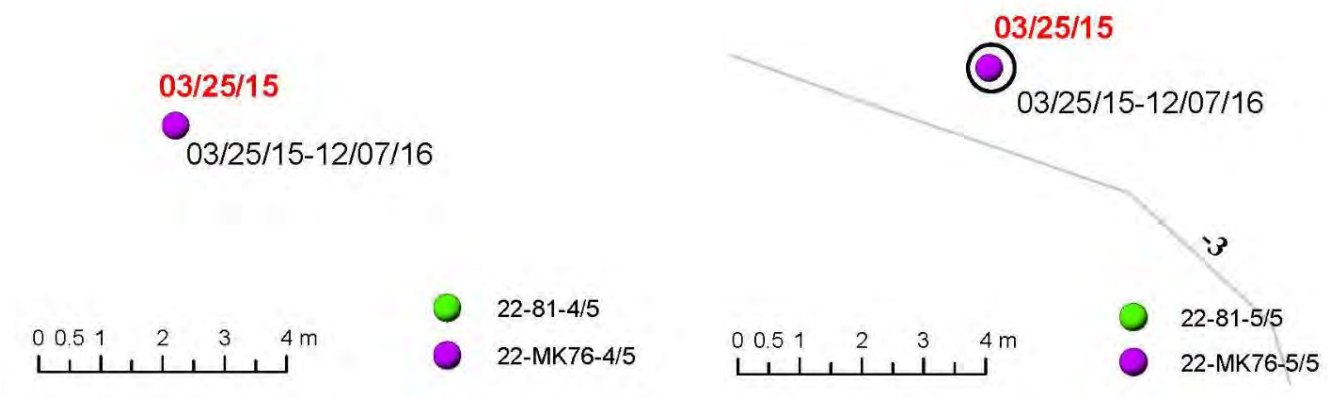

Figure K-25. Displacement of surrogates at Beach 22 (west, circled = date and location of deployment).

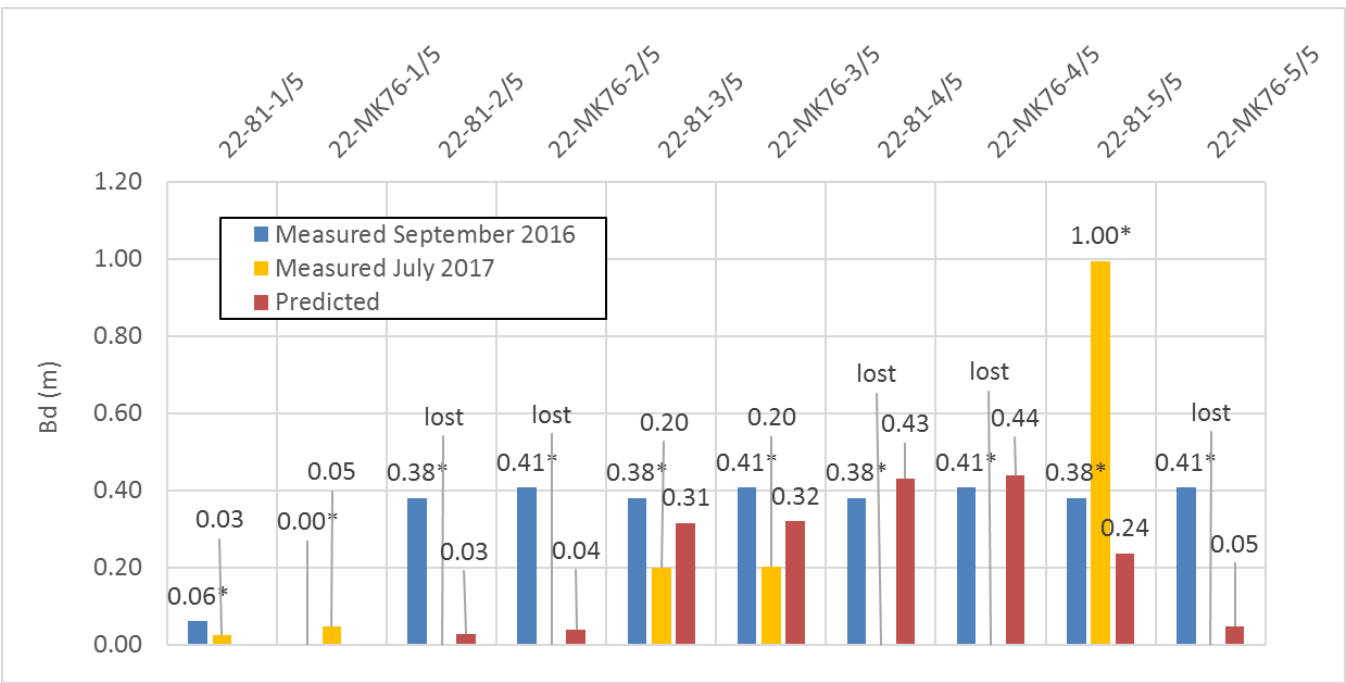

Figure K-26. Measured and predicted depths of burial of surrogates at Beach 22 (no prediction where bottom is coral, * estimated by divers or from underwater photos).

Table K-6. Summary of Burial and Mobility Analyses for Surrogates at Beach 22

ID	Bottom				Potential of MEC Burial and Mobility								Depth of Burial (B_d)				
					Typical				Maximum [b]				Measured		Predicted	B_d/D [c]	Time [d]
	Depth	Range [a]	Type	D_{50}	H_s	T_p	τ	MP	H_s	T_p	τ	MP	Sep-2016	Jul-2017			
22-81-1/5	6.19	0.00	Co	-	0.59	6.0	-	-	1.57	11.7	-	-	0.06*	0.03	-	0.54	-
22-MK76-1/5	6.09												0.00*	0.05		0.22	-
22-81-2/5	2.74	0.00	S	0.34	0.35	5.1	**1.21**	0.03	0.97	10.4	**6.88**	0.28	0.38*	lost	0.03	4.70	107
22-MK76-2/5								0.02				0.21	0.41*	lost	0.04	3.80	107
22-81-3/5	2.81	0.50	S	0.34	0.22	4.6	**0.55**	0.01	0.63	9.1	**3.24**	0.11	0.38*	0.20	0.31	3.59	177
22-MK76-3/5								0.01				0.08	0.41*	0.20	0.32	2.85	177
22-81-4/5	2.84	0.40	S	0.34	0.37	5.2	**1.23**	0.03	0.81	9.9	**4.96**	0.19	0.38*	lost	0.43	4.70	107
22-MK76-4/5								0.02				0.14	0.41*	lost	0.44	3.80	107
22-81-5/5	2.77	0.20	S	0.34	0.42	5.5	**1.62**	0.04	0.94	10.4	**6.42**	0.26	0.38*	1.00*	0.24	8.49	107
22-MK76-5/5		0.00						0.03				0.19	0.41*	lost	0.05	3.80	107

a. range of bottom change based on BDI surveys at surrogate location
b. winter 2015
c. based on average of measured B_d
d. days from deployment to fully buried

Dimensions in m, D_{50} in mm, T_p in seconds, τ in N/m^2
MEC surrogate diameters: 81 mm Mortar = 0.081 m, MK 76 Practice Bomb = 0.107 m
- no depth of burial prediction, and burial and mobility analysis where bottom is coral
* estimated by divers or from underwater photos

bold = exceeds critical, critical τ = 0.20 N/m^2 for D_{50}, critical MP = 0.39 for D/B_d = 10 (Friedrichs, 2015)

S = sand, Co = coral

τ = enhanced (due to surrogate/bottom interaction) wave-induced shear stress for 2015 conditions (assumed 2 x wave-induced shear stress)

- 22-81-1/5 and 22-MK76-1/5

  a) The surrogates were located on a coral bottom covered by a thin layer of sand, in relatively deep water and in area of relatively high waves, seaward of the depth of closure where the bottom did not change.

  b) The coral bottom prevented the self-burial, and it irregularity should have prevented/limited the mobility of these surrogates.

  c) The surrogate surveys (tracking) showed displacements with no dominant direction, and of the same magnitude as the expected positioning resolution of the vessel used for the surveys.

  d) The considerations above, depth of burial measurements and estimates from underwater photos support the notion that these surrogates did not move or self-bury.

- 22-81-2/5 and 22-MK76-2/5; and 22-81-3/5 and 22-MK76-3/5

  a) The surrogates were located on a sandy bottom, in relatively shallow water and in an area of relatively low waves,

     i) 22-81-2/5 and 22-MK76-2/5 seaward of the depth of closure where the bottom exhibited no changes, and

     ii) 22-81-3/5 and 22-MK76-3/5, landward of the depth of closure where the bottom exhibited changes.

  b) For all surrogates, the enhanced shear stresses (due to typical waves and surrogate/bottom interaction) exceeded the bottom sediment critical shear stress suggesting that typical conditions were conducive to the self-burial of these surrogates.

  c) For all surrogates, the average MPs did not exceed the critical MP suggesting that typical conditions were not conducive to the mobility of these surrogates.

  d) The surrogate surveys (tracking) showed no displacements, or minor displacements with no dominant direction and of the same magnitude as the expected positioning resolution of the vessel used for the surveys.

  e) The considerations above, and depth of burial estimated from underwater photos support the notion that these surrogates did not move and self-buried initially, and deeper afterwards by:

     i) 22-81-2/5 and 22-MK76-2/5 by bottom fluidization, and

     ii) 22-81-3/5 and 22-MK76-3/5 by beach-wide changes.

     The depth of burial of 22-81-2/5 and 22-MK76-2/5, estimated in the order of 4 to 5 diameters in an area of no bottom change and relatively low waves, could have possibly been produced by bottom fluidization. The sediment size at the location of the surrogate is unknown, and sampling and analysis would be required to confirm this hypothesis. Surrogates 22-81-2/5 and 22-MK76-2/5 were lost.

  f) For all surrogates, the maximum MPs occurred in the winter (February 2015) and did not exceed the critical MP suggesting that typical winter conditions were not be conducive to the mobility of these surrogates.

- 22-81-4/5 and 22-MK76-4/5; and 22-81-5/5 and 22-MK76-5/5

  a) The surrogates were located on a sandy bottom, in relatively shallow water and in an area of relatively low waves,

     i) 22-81-4/5 and 22-MK76-4/5 were located landward of the depth of closure where the bottom exhibited changes, and

     ii) 22-81-5/5 and 22-MK76-5/5 were located in the vicinity of the depth of closure where the bottom exhibited minor changes.

b) For all surrogates, the enhanced shear stresses (due to typical waves and surrogate/bottom interaction) exceeded the bottom sediment critical shear stress suggesting that typical conditions were conducive to the self-burial of these surrogates.

c) For all surrogates, the average MPs did not exceed the critical MP suggesting that typical conditions were not conducive to the mobility of these surrogates.

d) The surrogate surveys (tracking) showed no displacements.

e) The considerations above, and depth of burial estimated from underwater photos support the notion that these surrogates did not move, but self-buried to a shallow depth initially, and deeper afterwards,

   i) 22-81-4/5 and 22-MK76-4/5, by beach-wide bottom changes and/or bottom fluidization, and

   ii) 22-81-5/5 and 22-MK76-5/5 by bottom fluidization. The depth of burial for these surrogates, estimated in the order of 4 to 8 diameters in this area of minor bottom change and relatively low waves, could have possibly been produced by bottom fluidization. The grain size diameter of the sediment at the location of the surrogates is unknown and sampling and analysis would be required to confirm this hypothesis.

   All surrogates, but 22-81-5/5 were lost.

f) For all surrogates, the maximum MPs occurred in the winter (February 2015) and did not exceed the critical MP suggesting that typical winter conditions were not be conducive to the mobility of these surrogates.

North EMA and SIA UXO 7
Beach 24

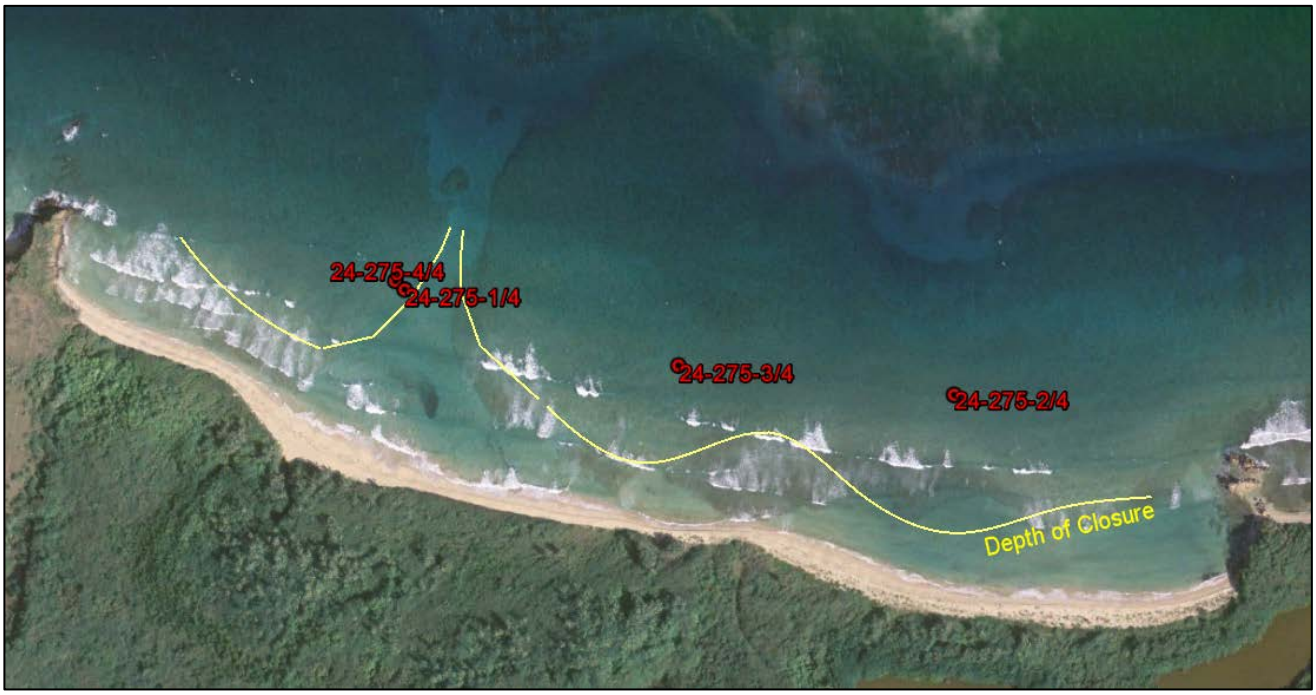

Figure K-27. Surrogate deployment locations and depth of closure at Beach 24.

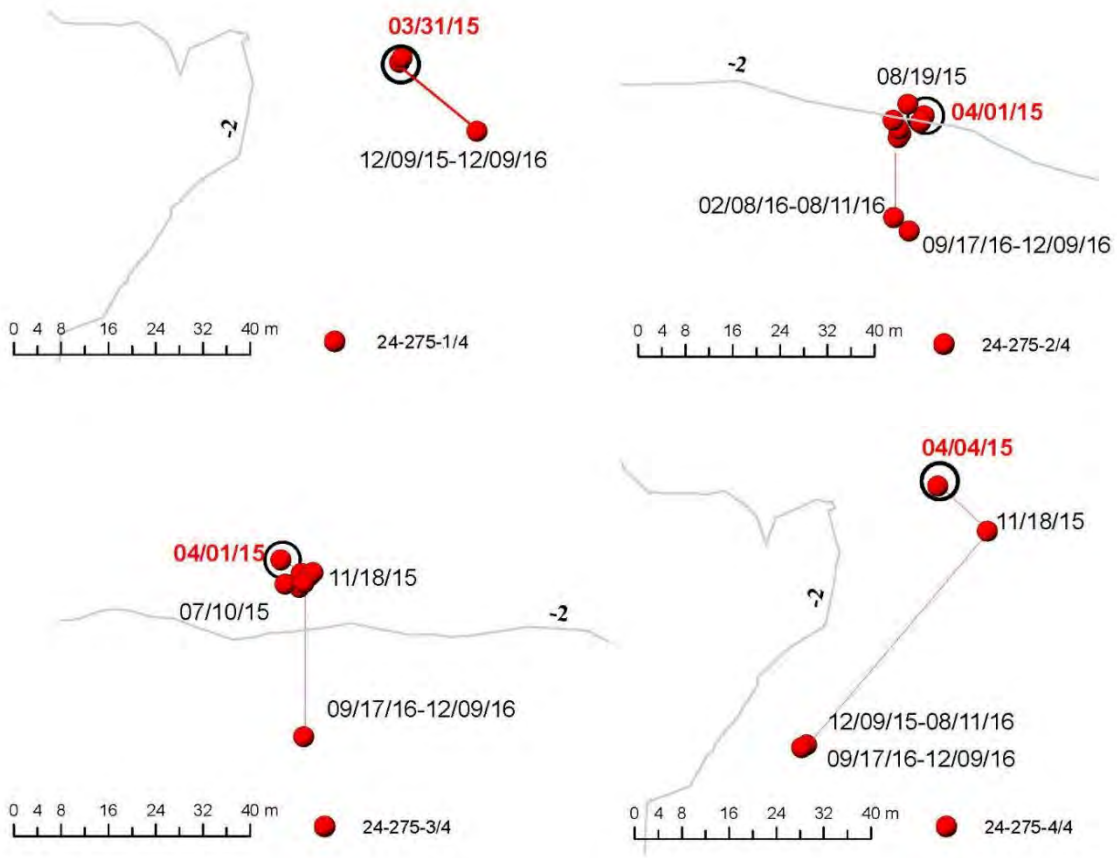

Figure K-28. Displacement of surrogates at Beach 24 (circled = date and location of deployment).

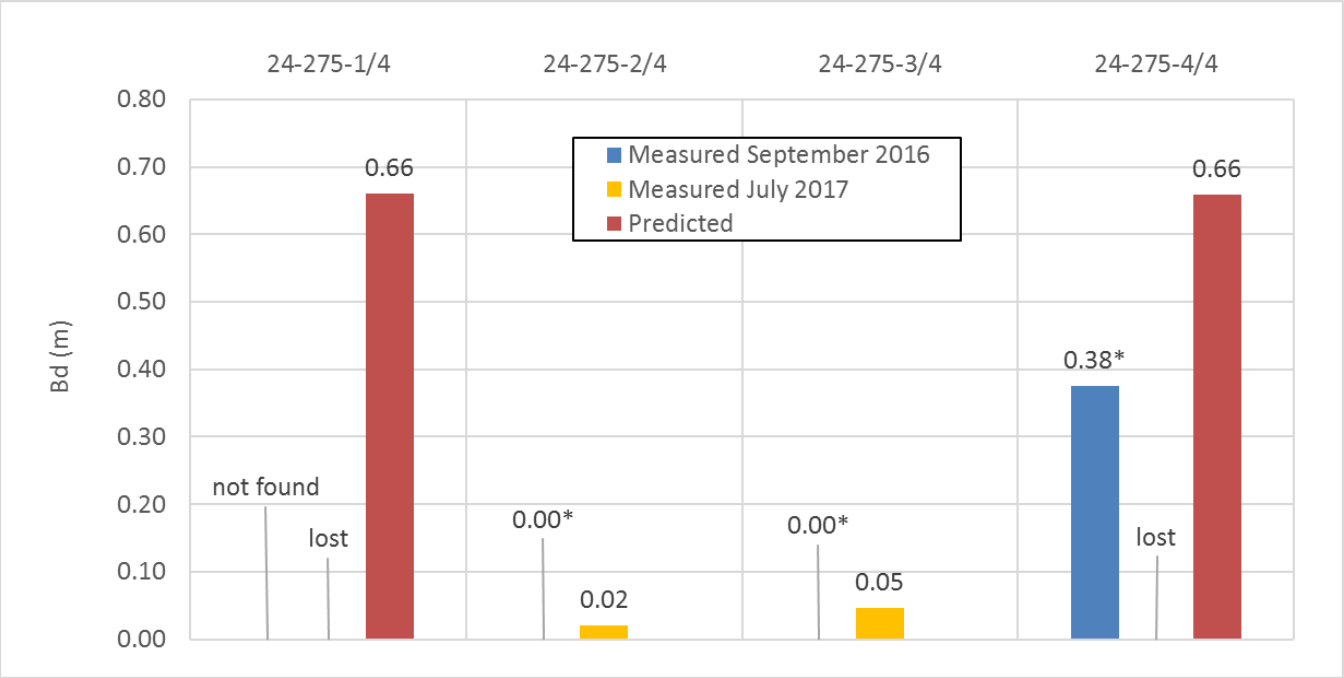

Figure K-29. Measured and predicted depths of burial of surrogates at Beach 24 (no prediction where bottom is coral, * estimated by divers).

Table K-7. Summary of Burial and Mobility Analyses for Surrogates at Beach 24

ID	Bottom				Potential of MEC Burial and Mobility								Depth of Burial (B_d)				
					Typical				Maximum [b]				Measured		Predicted	B_d/D [c]	Time [d]
	Depth	Range [a]	Type	D_{50}	H_s	T_p	τ	MP	H_s	T_p	τ	MP	Sep-2016	Jul-2017			
24-275-1/4	2.69	0.60	S	0.30	0.59	5.7	**2.92**	**2.46**	1.27	11.5	**10.81**	**13.04**	not found	lost	0.66	-	101
24-275-2/4	2.30	0.00	Co	-	0.53	5.6	-	-	1.15	11.5	-	-	0.00*	0.02	-	0.14	-
24-275-3/4	2.42	0.00	Co		0.54	5.5			1.14	11.1			0.00*	0.05		0.30	-
24-275-4/4	2.48	0.60	S	0.30	0.55	5.4	**2.77**	**2.08**	1.10	11.0	**9.07**	**9.57**	0.38*	lost	0.66	4.95	100

a. range of bottom change based on BDI surveys at surrogate location
b. winter 2015
c. based on average of measured B_d
d. days from deployment to fully buried

Dimensions in m, D_{50} in mm, T_p in seconds, τ in N/m^2
MEC surrogate diameter: 2.75-inch Rocket = 0.076 m
- no depth of burial prediction, and burial and mobility analysis where bottom is coral
* estimated by divers

bold = exceeds critical, critical τ = 0.20 N/m^2 for D_{50}, critical MP = 0.39 for D/B_d = 10 (Friedrichs, 2015)

S = sand, Co = coral

τ = enhanced (due to surrogate/bottom interaction) wave-induced shear stress for 2015 conditions (assumed 2 x wave-induced shear stress)

- 24-275-1/4 and 24-275-4/4

  a) The surrogates were located on a sandy bottom, in relatively shallow water and in an area of relatively high waves, in the vicinity of a sand channel where the bottom exhibited changes.

  b) The enhanced shear stresses (due to typical waves and surrogate/bottom interaction) exceeded the bottom sediment critical shear stress suggesting that typical conditions were conducive to the self-burial of these surrogates.

  c) For both surrogates, the average MPs were higher than the critical MP suggesting that typical conditions were conducive to the mobility of these surrogates.

  d) For both surrogates, the surveys (tracking) showed relatively large displacements in cross-shore and longshore directions, which exceeded the magnitude of the expected positioning resolution of the vessel used for the surveys.

  e) The considerations above, and depth of burial estimated by divers support the notion that these surrogates moved, self-buried to a shallow depth initially, and deeper afterwards due to bottom changes in the sand channel. Surrogates 24-275-1/4 and 24-275-4/4 were lost.

  f) For both surrogates, the maximum MPs occurred in the winter (February 2015) and exceeded the critical MP suggesting that typical winter conditions would be conducive to the mobility of this type of surrogates.

- 24-275-2/4 and 24-275-3/4

  a) The surrogates were located on a coral bottom, in relatively shallow water and in area of relatively high waves, seaward of the depth of closure where the bottom did not change.

  b) The coral bottom prevented the self-burial, and it irregularity should have prevented/limited the mobility of these surrogates.

  c) The surveys (tracking) showed relatively large landward displacements, which exceeded the magnitude of the expected positioning resolution of the vessel used for the surveys.

  d) The considerations above, and diver's assessment supports the notion that these surrogates moved. The surrogates were found resting on the coral.

South SIA UXO 8
Beach 1

Figure K-30. Surrogate deployment locations and depth of closure at Beach 1.

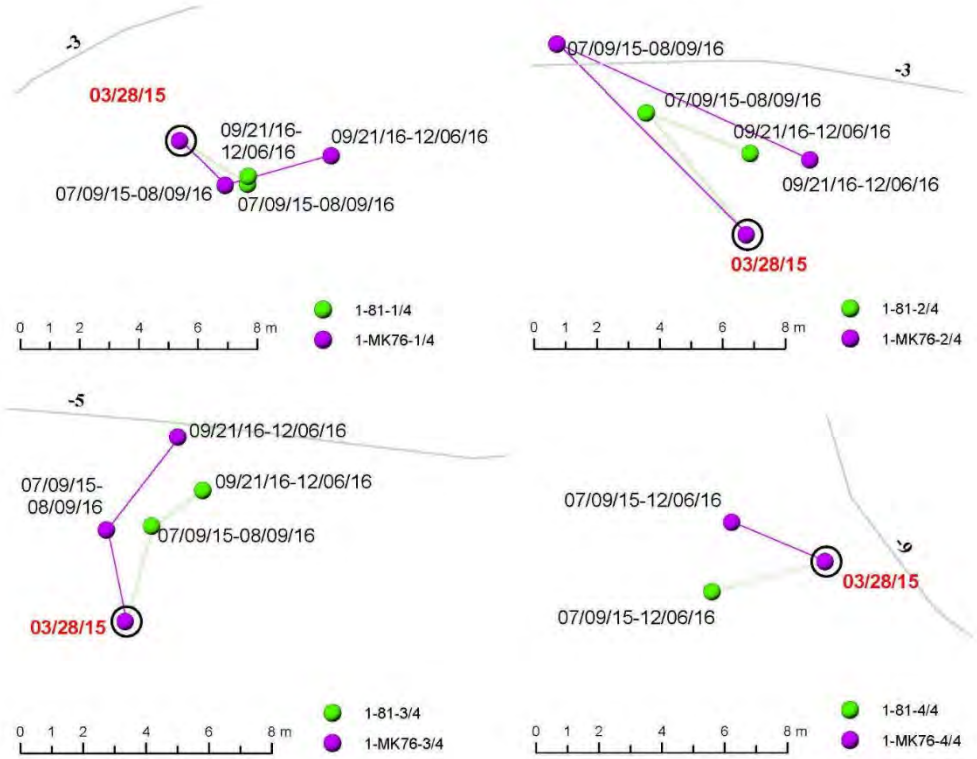

Figure K-31. Displacement of surrogates at Beach 1 (circled = date and location of deployment).

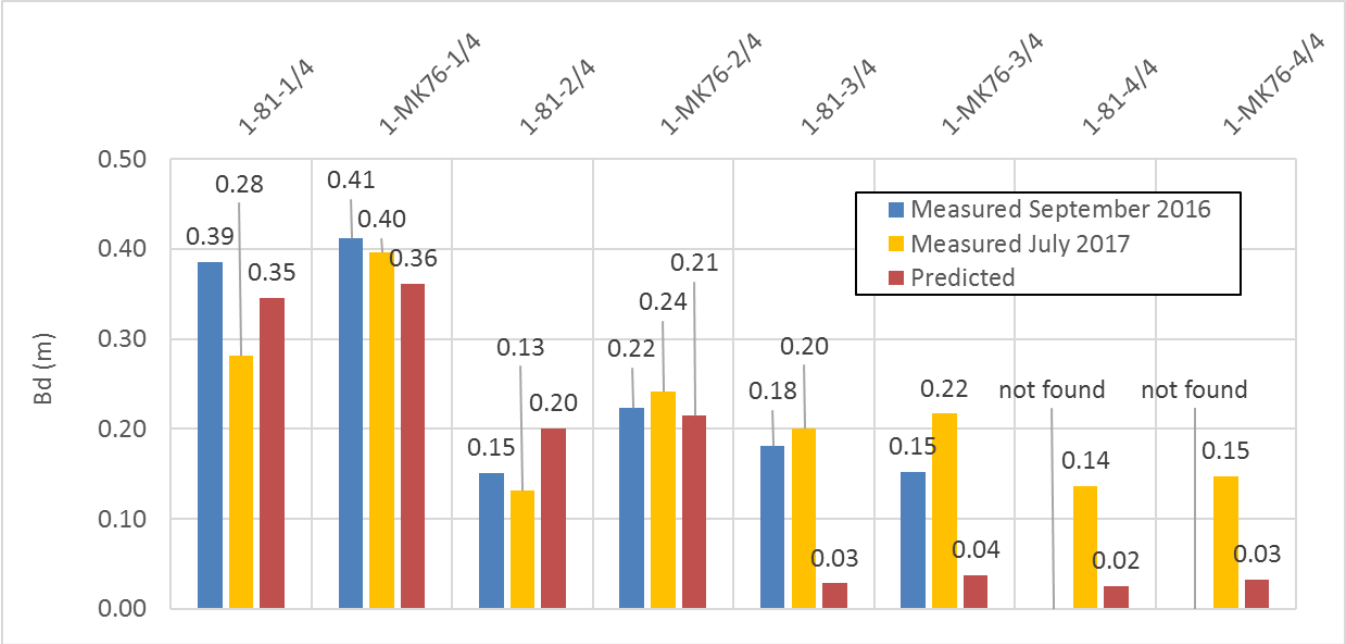

Figure K-32. Measured and predicted depths of burial of surrogates at Beach 1.

Table K-8. Summary of Burial and Mobility Analyses for Surrogates at Beach 1

ID	Bottom				Potential of MEC Burial and Mobility								Depth of Burial (B_d)				
					Typical				Maximum [b]				Measured		Predicted	B_d/D [c]	Time [d]
	Depth	Range [a]	Type	D_{50}	H_s	T_p	τ	MP	H_s	T_p	τ	MP	Sep-2016	Jul-2017			
1-81-1/4	4.00	0.30	S	0.20	0.52	5.2	**1.32**	0.04	1.70	6.9	**11.15**	**0.50**	0.39	0.28	0.35	4.8	103
1-MK76-1/4								0.03				0.37	0.41	0.40	0.36	3.9	103
1-81-2/4	3.00	0.16	S	0.20	0.39	5.0	**1.15**	0.03	1.38	6.5	**10.39**	**0.46**	0.15	0.13	0.20	1.9	103
1-MK76-2/4								0.03				0.34	0.22	0.24	0.21	2.1	103
1-81-3/4	5.60	0.00	S	0.20	0.47	5.3	**0.72**	0.02	1.75	6.8	**7.82**	0.33	0.18	0.20	0.03	2.2	103
1-MK76-3/4								0.01				0.25	0.15	0.22	0.04	1.4	103
1-81-4/4	9.22	0.00	S	0.20	0.69	5.5	**0.61**	0.02	2.4	7.0	**7.19**	0.31	not found	0.14	0.02	1.68	103
1-MK76-4/4								0.01				0.23	not found	0.15	0.03	1.37	103

a. range of bottom change based on BDI surveys at surrogate location
b. Tropical Storm Erika on August 28, 2015
c. based on average of measured B_d
d. days from deployment to fully buried

Dimensions in m, D_{50} in mm, T_p in seconds, τ in N/m^2
MEC surrogate diameters: 81 mm Mortar = 0.081 m, MK 76 Practice Bomb = 0.107 m

bold = exceeds critical, critical τ = 0.15 N/m^2 for D_{50}, critical MP = 0.39 for D/B_d = 10 (Friedrichs, 2015)

S = sand

τ = enhanced (due to surrogate/bottom interaction) wave-induced shear stress for 2015 conditions (assumed 2 x wave-induced shear stress)

- <u>1-81-1/4 and 1-MK76-1/4; and 1-81-2/4 and 1-MK76-2/4</u>

  a) The surrogates were located on a sandy bottom, in relatively shallow water and in an area of relatively high waves, landward of the depth of closure where the bottom exhibited changes.

     1-81-2/4 and 1-MK76-2/4 were aligned with the ephemeral stream that conveys rainfall collected in the watershed to the east of Cerro Matias Jalobre. Because rainfall in 2015 was lower than average, the stream did not breach the beach nor it supplied sediment that could have affected the surrogates and the bottom in the nearshore.

  b) For all surrogates, the enhanced shear stresses (due to typical waves and surrogate/bottom interaction) exceeded the bottom sediment critical shear stress suggesting that typical conditions were conducive to the self-burial of these surrogates.

  c) For all surrogates, the average MPs did not exceed the critical MP suggesting that typical conditions were not conducive to the mobility of these surrogates.

  d) The surrogate surveys (tracking) showed, for:

     i) 1-81-1/4 and 1-MK76-1/4, displacements in the longshore direction, different than the expected cross-shore direction. However, these were of the same magnitude as the expected positioning resolution of the vessel used for the surveys,

     ii) 1-81-2/4 and 1-MK76-2/4, a couple of relative large displacements in the cross-shore direction, landward first and seaward afterwards, but these did not correspond with the occurrence of a storm. Displacements were of the same magnitude as the expected positioning resolution of the vessel used for the surveys.

  e) The considerations above, the range of bottom vertical change measured at the location of the surrogates and depth of burial measurements support the notion that these surrogates did not move, but self-buried to a shallow depth initially, and deeper afterwards due to beach-wide bottom changes.

  f) For all surrogates, the maximum MPs would have been reached during Tropical Storm Erika and would have exceeded or been comparable to the critical MP. No displacements were observed because the surrogates were likely self-buried already, and buried by a berm formed in the nearshore by sediment transported seaward by the storm.

- <u>1-81-3/4 and 1-MK76-3/4</u>

  a) The surrogates were located on a sandy bottom, in an area of relatively high waves, and seaward of the depth of closure where the bottom exhibited no changes. The surrogates were aligned with the ephemeral stream that conveys rainfall collected in the watershed to the east of Cerro Matias Jalobre. Because rainfall in 2015 was lower than average, the stream did not breach the beach nor it supplied sediment that could have affected the bottom in nearshore and the surrogates.

  b) The enhanced shear stresses (due to typical waves and surrogate/bottom interaction) exceeded the bottom sediment critical shear stress suggesting that typical conditions were conducive to the self-burial of these surrogates.

  c) For both surrogates, the average MPs did not exceed the critical MP suggesting that typical conditions were not conducive to the mobility of these surrogates.

  d) The surrogate surveys (tracking) showed displacements in the landward direction, but were of the same magnitude as the expected positioning resolution of the vessel used for the surveys.

  e) The considerations above, and depth of burial measurements support the notion that these surrogates did not move and self-buried to a shallow depth.

f) For both surrogates, the maximum MPs would have been reached during Tropical Storm Erika, but would have not exceeded the critical MP. If the surrogates were not buried, it is possible that they would have not moved during the storm.

- 1-81-4/4 and 1-MK76-4/4

a) The surrogates were located on a sandy bottom covered with some seagrass, in relatively deep water and in an area of relatively high waves, seaward of the depth of closure where the bottom exhibited no changes.

b) The enhanced shear stresses (due to typical waves and surrogate/bottom interaction) exceeded the bottom sediment critical shear stress suggesting that typical conditions were conducive to the self-burial of these surrogates.

c) For both surrogates, the average MPs did not exceed the critical MP suggesting that typical conditions were not conducive to the mobility of these surrogates.

d) The surrogate surveys (tracking) showed displacements in the landward direction, but were of the same magnitude as the expected positioning resolution of the vessel used for the surveys.

e) The considerations above, supports the notion that these surrogates did not move and self-buried to a shallow depth.

f) For both surrogates, the maximum MPs would have been reached during Tropical Storm Erika, but would have not exceeded the critical MP. If the surrogates were not buried, it is possible that they would have not moved during the storm.

South SIA UXO 8
Beach 19

Figure K-33. Surrogate deployment locations and depth of closure at Beach 19 (19-538-1/3 mislabeled 19-538-2/2).

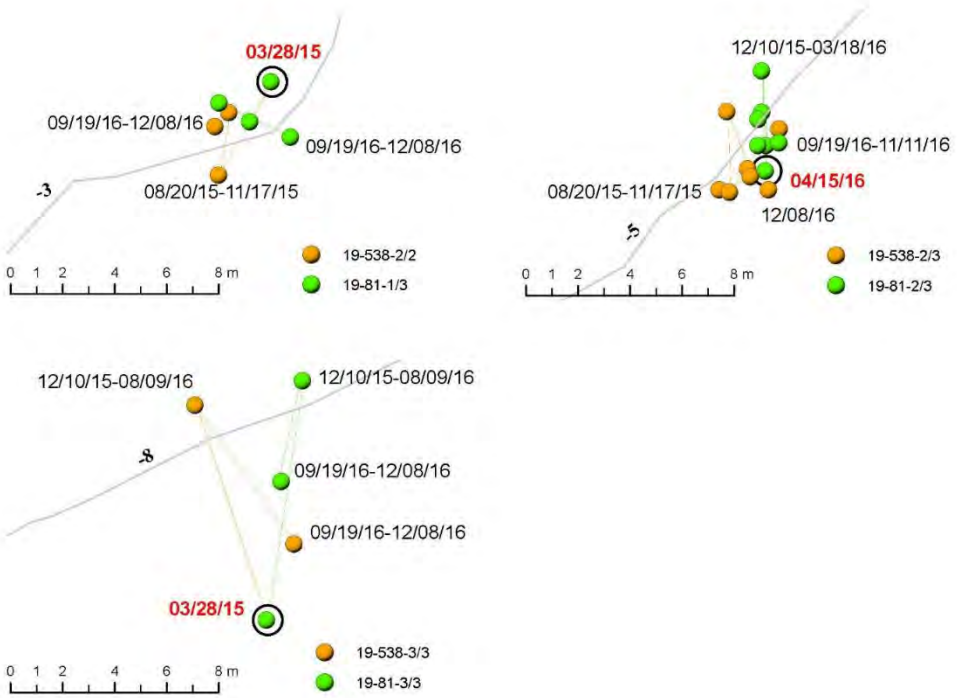

Figure K-34. Displacement of surrogates at Beach 19 (circled = date and location of deployment).

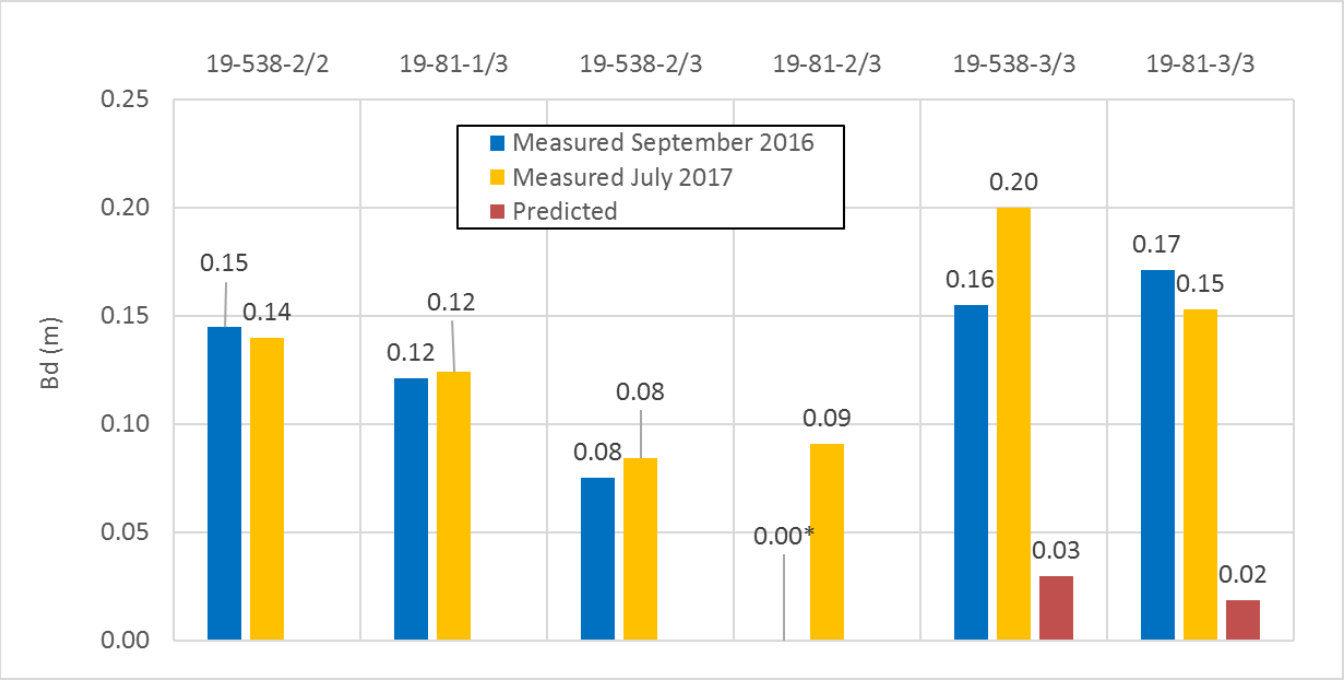

Figure K-35. Measured and predicted depths of burial of surrogates at Beach 19 (no prediction where bottom is seagrass, * estimated from underwater photos).

Table K-9. Summary of Burial and Mobility Analyses for Surrogates at Beach 19

ID	Bottom				Potential of MEC Burial and Mobility								Depth of Burial (B_d)				
					Typical				Maximum [b]				Measured		Predicted	B_d/D [c]	Time [d]
	Depth	Range [a]	Type	D_{50}	H_s	T_p	τ	MP	H_s	T_p	τ	MP	Sep-2016	Jul-2017			
19-538-2/2	3.25	0.00	SGrs	-	0.22	5.3	-	-	0.88	7.2	-	-	0.15	0.14	-	1.1	376
19-81-1/3	3.28												0.12	0.12		1.5	376
19-538-2/3	5.22	0.00	SGrs	-	0.44	5.5	-	-	1.9	7.06	-	-	0.08	0.08	-	0.6	-
19-81-2/3	5.20												0.00*	0.09		0.0	-
19-538-3/3	8.28	0.00	S	0.60	0.73	5.7	**1.23**	0.02	2.79	7.5	**15.04**	0.33	0.16	0.20	0.03	1.2	376
19-81-3/3	8.25							0.03				**0.53**	0.17	0.15	0.02	2.1	376

a. range of bottom change based on BDI surveys at surrogate location
b. Tropical Storm Erika on August 28, 2015
c. based on average of measured B_d
d. days from deployment to fully buried

Dimensions in m, D_{50} in mm, T_p in seconds, τ in N/m^2
MEC surrogate diameters: 5-inch 38 Caliber Projectile = 0.130 m, 81 mm Mortar = 0.081 m
- no depth of burial prediction, and burial and mobility analysis where bottom is seagrass
* estimated from underwater photos

bold = exceeds critical, critical τ = 0.30 N/m^2 for D_{50}, critical MP = 0.39 for D/B_d = 10 (Friedrichs, 2015)

S = sand, SGrs = seagrass

τ = enhanced (due to surrogate/bottom interaction) wave-induced shear stress for 2015 conditions (assumed 2 x wave-induced shear stress)

- 19-538-2/2 and 19-81-1/3; and 19-538-2/3 and 19-81-2/3
  a) The surrogates were located on a sandy bottom covered with seagrass, in relatively shallow water and in area of relatively low waves, seaward of the depth of closure where the bottom exhibited no changes.
  b) The seagrass should have prevented/limited the self-burial and mobility of these surrogates.
  c) The surrogate surveys (tracking) showed displacements with no dominant direction, and of the same magnitude as the expected positioning resolution of the vessel used for the surveys.
  d) The considerations above support the notion that these surrogates did not move. For all surrogates, the inspection of underwater photos verified the depth of burial measurement and suggested that burial may have occurred by the settlement of sediment in the area.
- 19-538-3/3 and 19-81-3/3
  a) The surrogates were located on a sandy bottom, in relatively deep water and in an area of relatively high waves, seaward of the depth of closure where the bottom exhibited no changes.
  b) The enhanced shear stresses (due to typical waves and surrogate/bottom interaction) exceeded the bottom sediment critical shear stress suggesting that typical conditions were conducive to the self-burial of these surrogates.
  c) For both surrogates, the average MPs did not exceed the critical MP suggesting that typical conditions were not conducive to the mobility of these surrogates.
  d) The surrogate surveys (tracking) showed displacements in the cross-shore direction, and of the same magnitude as the expected positioning resolution of the vessel used for the surveys.
  e) The considerations above, and depth of burial measurements support the notion that these surrogates did not move and self-buried to a shallow depth.
  f) For both surrogates, the maximum MPs were reached during Tropical Storm Erika.
     i) For 19-538-3/3, the MP did not exceed the critical MP.
     ii) For 19-81-3/3, the MP exceeded the critical MP.

Appendix L
Responses to Regulator Comments

Responses to EPA Comment on the Draft Beach Dynamics Investigation Report

Atlantic Fleet Weapons Training Area – Vieques
Former Naval Ammunition Support Detachment
Former Vieques Naval Training Range
Vieques, Puerto Rico

1. **Table 4-2, MEC Surrogate Types and Nominal Characteristics:** This table lists one munitions and explosives of concern (MEC) surrogate as "8-mm Mortar," however, this listing is in error as the surrogate type should be identified as "81-mm Mortar." Revise this table accordingly.

   Navy Response: The table has been revised as requested.

Responses to PREQB Comments on the Draft Beach Dynamics Investigation Report

Atlantic Fleet Weapons Training Area – Vieques
Former Naval Ammunition Support Detachment
Former Vieques Naval Training Range
Vieques, Puerto Rico

GENERAL COMMENTS

1. UXO 16 WAA, Section 3.3.5, Surface Impact Area: The referenced section indicates the migration of MEC is or is suspected to be occurring. The conclusions provided by the Beach Dynamics Investigation report indicates that is not likely to be true. Will the WAA report be revised to reflect the conclusions in this report?

Navy Response: Given that the hypothesis in the WAA Report was based on observation of geophysical anomaly densities and that the conclusions of the Beach Dynamics Investigation were based on measured sand and munitions surrogate transport (which indicate westward migration of munitions is unlikely), the WAA Report was revised to remove the statement regarding potential westward migration.

2. Section 5 (Results and Analysis) provides an overview of the types of data collected and analyses performed with limited presentation of the results. For example, water level and rainfall data are presented, but there is no presentation of wave data. Please supplement this section of the report with plots of observed wave statistics over the time period measured.

Navy Response: The general wave conditions and impacts on the various beaches are summarized in Tables 5-3 through 5-15.

3. Section 6 (Summary and Conclusions) of the report states that the Beach Dynamics Investigation (BDI) approach included measurement of waves and assessment of "their impacts on beach changes, and burial and mobility of MEC." While data regarding waves, beach changes, and MEC burial/mobility were collected throughout the BDI and used to support the general conclusions presented in Section 6.2, the assessment of the relationship between these observations is not adequately described. Please amend the report to further discuss these relationships.

More specifically, please consider elaborating in Section 5 (Results and Analysis) on the Navy's assessment of the following relationships noted in Section 6.1 – BDI Summary:

- Collection of concurrent water level measurements from NOAA Stations to assess the impact of water levels on beach changes.
- Continuous rainfall measurements to assess precipitation impacts on surface water runoff, beach changes, and burial and mobility of MEC.
- Monthly MEC surrogate surveys to evaluate burial and mobility of underwater MEC in the nearshore environment under the effect of beach changes, waves, currents, and water levels.
- Metocean field observations to help understand these conditions relative to measured beach changes.

PREQB feels that the additional discussion in the text will provide a better connection of the raw data to the conclusions presented in Section 6.

Navy Response: Please refer to Tables 5-3 through 5-15 regarding an evaluation of surface water runoff, wave conditions, and metocean field observations at each beach evaluated. Section 5.6 summarizes the results of the MEC surrogate surveys. Table 6-1 further describes the relationship between wave conditions and beach changes.

PAGE-SPECIFIC COMMENTS

1. Page 3-2, Section 3.3.2 - Waves, Paragraph 2: The wave climate is reported as 1 to 2-meter waves with periods of 5 to 10 seconds. Please clarify if this is based on the measurements performed during this investigation or other data, citing applicable references (as appropriate).

Navy Response: Please refer to the opening paragraph in Section 3: "The general setting of the coastal and marine environment at Vieques, summarized in the subsections that follow, is based on information obtained mainly from the following sources: Bauer et al. (2008), Geo-Marine Inc. (2005), Morelock et al. (2014), and the Caribbean Fishery Management Council (2004). Summaries and adaptations of this information are complemented with observations made during a site visit performed by CH2M between March 11 and 15, 2013 (CH2M, 2014)."

2. Page 3-2, Section 3.3.2, Third Paragraph, Last sentence: "… storms and cold fronts farther north, produce 3 to 3.5 m, 12 to 16 second waves that often…"

Is the "12 to 16 second waves" referring to the periods between the waves? If so, please revise the sentence to specify the time being referred to as the period between each wave.

Navy Response: Yes, the phrase is referring to the wave periods. The sentence has been clarified as requested.

3. Page 5-1, Section 5: The individual assessments of each beach in Tables 5-3 through 5-15 and plan view Figures 5-12 through 5-37 are valuable; however, please also include a reference(s) to Appendix J to alert the reader to the beach cross section profiles.

Navy Response: A reference to Appendix J has been added in Section 5.

4. Page 5-2, Section 5.2, First Paragraph, First Sentence: Place a space between September 29, and 2016.

Navy Response: Revised as requested.

5. Page 5-3, Section 5.2 – Storms: The four bullets on Page 5-3 provided estimates of significant wave heights on the beaches of Vieques, presumably from the wave hindcast. Please clarify the water depth assumed for the wave heights reported and if these are the wave heights at the time of breaking.

Navy Response: The following information has been added to Section 5.2: "Significant wave heights were estimated from a wave hindcast, as noted above. Because the wave model was coupled with a hydrodynamic model that simulated the time- and space-varying water levels, water depths also varied. In the bullet list, ranges of significant wave heights are given to provide a general idea of the magnitude of the wave heights in the nearshore at the Beach Dynamics Investigation beaches. For additional detail, please see Figures I-16 through I-35 in Appendix I."

6. Page 5-3, Section 5.3 – Water Levels: To supplement the discussion of various depth of burial formulas please include, at a minimum, the equation from Demir et al. (2007), which was proposed as the most appropriate equation.

Navy Response: Section 5.3 discusses water level observations made during the Beach Dynamics Investigation; burial formulas are not relevant to this discussion.

7. Page 5-6, Section 5.6, Third Paragraph: This paragraph discusses the predicted depth of burial formulas. Since the predicted burial depths are presented in the report (specifically in Appendix F) and are compared to the actual burials over time. What is the time period represented by this formula in which a surrogate reaches its maximum burial depth?

Navy Response: The formulas are not a function of time.

8. Page 5-6, Section 5.6, Third Paragraph: "This is not the case for the MEC surrogates…..densities of seagrass, rocks, shells, etc.)" Place a period at the end of the sentence.

Navy Response: A period has been added.

9. Page 6-1, Section 6 – Summary and Conclusions: The conclusions in Section 6 of the report identify changes in beach morphology due to wave activity, but no discussion of how the observed wave climate was related to the observed changes in beach cross section is provided in either the body of the report or the associated appendices. Please include a discussion in the revised report.

Navy Response: Please see the response to General Comment #2.

TABLE-SPECIFIC COMMENTS

1. Table 3-2 – Significant Wave Height and Storm Surge at Vieques from Various Return Periods: Please acknowledge the source of these wave estimates in a footnote to Table 3-2.

Navy Response: A footnote has been added as requested. Section 3.3.6 states that these are according to the Caribbean Disaster Mitigation Project (2000).

2. Table 4-1: Please add definitions for Length, Wave Exposure and Dynamics to the tables footer.

Navy Response: This information has been added as requested.

APPENDIX-SPECIFIC COMMENTS

<u>Appendix A (Wave Measurement) and Appendix I (Wave Analyses)</u>

1. The wave data shown is limited to histograms of significant wave height, period, and direction as a function of season. In assessing the wave data, it would be useful and PREQB requests that time series plots of these variables, as well as representative energy and directional spectra for the three deployment sites, be provided in the revised report.

Navy Response: Time series plots of wave height, period and direction will be added. Wave spectra were not measured.

2. Section 3 of Appendix I describes the wave modeling performed in conjunction with the impacts of Hurricane Maria. If this was the only modeling performed, please clarify how the typical wave fields at each beach, reported in Tables 5-3 through 5-15, were determined.

In addition, there is some discussion elsewhere in the draft report, most notable in Appendix K, of a 2015 wave hindcast. Please clarify if this or a simpler methodology was used to propagate the observed wave heights at the three AWAC stations onto the beaches. Please describe the appropriate methodology in the text and/or Appendix I.

Navy Response: The following has been added to Section 3 of Appendix I: "The wave conditions at each beach, reported in Tables 5-3 through 5-15, were estimated from observations and the 2015 wave hindcast.

The 2015 wave hindcast was developed with a spectral wave model propagating the wave heights measured in 2015 at the three AWAC locations to the beaches."

Appendix J (Beach Dynamics Results and Analysis)

1. The description of the analysis does not indicate how the depth of closure (or the landward limit of beach change) was determined from the profiles. In most cases, significant changes in bottom elevation can be seen seaward of the marked location of the depth of closure. Please clarify this discrepancy and the assumptions used in determining the depth of closure (and landward limit).

Navy Response: The first paragraph on page 5-5, Section 5 states that the depth of closure (and landward limit of beach change) were identified by evaluation of the measured profiles and through the analysis of aerial photos. Beyond the depth of closure, no significant changes in bottom elevation are expected in typical wave conditions. It is relatively simple to identify the depth of closure by visual inspection of profiles at beaches fronted by broad sandy bottoms, like Beach 1, where measured beach profiles would collapse at the depth of closure. However, this is not as straightforward at beaches which are fronted by combinations of sandy, reef and seagrass bottoms. Furthermore, there are inherent challenges in measuring the beach profiles precisely on a transect from a survey boat in a seaway, together with the "false" returns from seagrass and rocky bottoms, both of which affect the repeatability of the measurements, leading to the bottom changes noted beyond the depth of closure. However, in these instances the depth of closures identified represent a good approximation, sufficient for the objectives of the Beach Dynamics Investigation and use of its data. This information has been added to Section 5.

2. In addition to the envelope of beach changes indicated on the figures, inclusion of the individual measured transects is requested. An understanding of the temporal evolution of the beach profile is important in identifying whether the observed changes occur gradually or episodically, and what mechanisms are forcing those changes.

Navy Response: The Beach Dynamics Investigation was conducted to evaluate the changes in beach profiles at each transect, thereby generating a good understanding of the evolution of the beach profile based on the numerous surveys conducted. Appendix J is intended to provide the highest and lowest elevations of the beach profiles, since each individual profile will be contained within all the other profiles. Significant findings related to the temporal evolution are summarized in Tables 5-3 through 5-13, as applicable. For instance, the seasonal shoreline position change at Beach 24 is summarized in Table 5-11. Inclusion of a figure for every measured transect would be unnecessarily cumbersome for the report.

3. Discussion of the processes responsible for the observed changes is somewhat limited. To the degree feasible, please include a comparison of the profiles, coupled with an understanding of the wave climate from the wave measurements, to identify whether cross shore or along shore processes are responsible for the observed changes. This information would be valuable to the understanding of potential MEC migration.

Navy Response: Please see the response to General Comment #2.

Appendix K (MEC Surrogate Surveys Results and Analysis)

1. Section 1 – Prediction of Depth of Burial: Please provide the definition/equation for the Shields parameter.

Navy Response: This information has been added as requested.

2. Section 2 – Potential of Munitions Burial and Mobility: Figure K-2 indicates significant sensitivity of the critical MP value to the value of the D/Bd ratio. Therefore, please provide additional justification for the assumption of D/Bd = 10.

Navy Response: This information has been added as requested.

3. Figure K-1 – Predicted versus Measured Depth of Burial and Best Fit Line: Please indicate the methodology associated with the predicted burial on the Y-axis.

Navy Response: This information has been added as requested.

4. Figure K-9 – Displacement of Surrogates at Beach 2 (and similar figures): Please clarify in caption whether multiple dots of the same color are different measurements of the same surrogate, or different surrogates. In addition, please identify the meaning of the date ranges on the figure (e.g., 09/20/16 – 12/20/16).

Navy Response: The circle colors represent the different surrogate types, as shown in the legend, and the dates represent measurement dates, as indicated in the caption.

Navy Responses to PREQB Follow-up Comments
Draft Beach Dynamics Investigation Report

Atlantic Fleet Weapons Training Area – Vieques
Former Naval Ammunition Support Detachment
Former Vieques Naval Training Range
Vieques, Puerto Rico

With the exception of the comments provided below, the Navy's responses are acceptable pending confirmation that all necessary and appropriate revisions have been incorporated into the revised report.

GENERAL COMMENTS

1. PREQB General Comment 2: Section 5 (Results and Analysis) provides an overview of the types of data collected and analyses performed with limited presentation of the results. For example, water level and rainfall data are presented, but there is no presentation of wave data. Please supplement this section of the report with plots of observed wave statistics over the time period measured.

Navy Response: The general wave conditions and impacts on the various beaches are summarized in Tables 5-3 through 5-15.

PREQB Evaluation of Response: PREQB appreciates the clarification that the typical wave conditions observed on each beach that are tabulated in Tables 5-3 through 5-15; however, the intent of this comment was focused on the wave data from the three measurement locations discussed in Section 5.1. Please clarify how the typical wave conditions noted on Tables 5-3 through 5-15 were determined – presumably through propagation of the observed wave characteristics to shore via the wave model?

Navy Follow-up Response: The typical wave (and wind) conditions in Tables 5-3 through 5-15 were determined from the field observations presented in Appendix G. Wave conditions during Hurricane Maria were determined from the wave hindcast described in Appendix I. The report was revised to include this clarification.

2. PREQB General Comment 3: Section 6 (Summary and Conclusions) of the report states that the Beach Dynamics Investigation (BDI) approach included measurement of waves and assessment of "their impacts on beach changes, and burial and mobility of MEC." While data regarding waves, beach changes, and MEC burial/mobility were collected throughout the BDI and used to support the general conclusions presented in Section 6.2, the assessment of the relationship between these observations is not adequately described. Please amend the report to further discuss these relationships.

More specifically, please consider elaborating in Section 5 (Results and Analysis) on the Navy's assessment of the following relationships noted in Section 6.1 – BDI Summary:

- Collection of concurrent water level measurements from NOAA Stations to assess the impact of water levels on beach changes.
- Continuous rainfall measurements to assess precipitation impacts on surface water runoff, beach changes, and burial and mobility of MEC.
- Monthly MEC surrogate surveys to evaluate burial and mobility of underwater MEC in the nearshore environment under the effect of beach changes, waves, currents, and water levels.
- Metocean field observations to help understand these conditions relative to measured beach changes.

PREQB feels that the additional discussion in the text will provide a better connection of the raw data to the conclusions presented in Section 6.

Navy Response: Please refer to Tables 5-3 through 5-15 regarding an evaluation of surface water runoff, wave conditions, and metocean field observations at each beach evaluated. Section 5.6 summarizes the results of the MEC surrogate surveys. Table 6-1 further describes the relationship between wave conditions and beach changes.

PREQB Evaluation of Response: Tables 5-3 through 5-15 provide a good summary of observations for each site; however, particularly with respect to "concurrent water level measurements from NOAA Stations", "continuous rainfall measurements", and "metocean field observations" there is no direct connection from the data to the conclusions drawn. Please describe the data connections in the revised text.

Navy Follow-up Response: Tables 5-3 through 5-15 (and Table 6-1) include conclusions about the impact of rainfall (indirectly through surface water runoff) and metocean (wind and wave) field observations on the observed beach changes. Water level changes during the BDI were typical (see Section 5.3). The conclusions drawn are based on both quantitative and qualitative evaluation of the data, which is the subject of the report as a whole. There is no conclusion drawn based on any particular data point; it is the accumulation of the data, representing the multitude of factors that together drive beach changes.

PAGE-SPECIFIC COMMENTS

1. PREQB Page-Specific Comment 1, Page 3-2, Section 3.3.2 - Waves, Paragraph 2: The wave climate is reported as 1 to 2-meter waves with periods of 5 to 10 seconds. Please clarify if this is based on the measurements performed during this investigation or other data, citing applicable references (as appropriate).

Navy Response: Please refer to the opening paragraph in Section 3: "The general setting of the coastal and marine environment at Vieques, summarized in the subsections that follow, is based on information obtained mainly from the following sources: Bauer et al. (2008), Geo-Marine Inc. (2005), Morelock et al. (2014), and the Caribbean Fishery Management Council (2004). Summaries and adaptations of this information are complemented with observations made during a site visit performed by CH2M between March 11 and 15, 2013 (CH2M, 2014)."

PREQB Evaluation of Response: Clarification of the source is appreciated; however, please clarify in the text if these values are consistent with the data collected during the study.

Navy Follow-up Response: Clarification has been added that the values are consistent with observations and data collected during the BDI.

2. PREQB Page-Specific Comment 6, Page 5-3, Section 5.3 – Water Levels: To supplement the discussion of various depth of burial formulas please include, at a minimum, the equation from Demir et al (2007), which was proposed as the most appropriate equation.

Navy Response: Section 5.3 discusses water level observations made during the Beach Dynamics Investigation; burial formulas are not relevant to this discussion.

PREQB Evaluation of Response: The response is correct in that the comment actually applies to Section 5.6 rather than Section 5.3 of the draft document. As noted in the original comment, please include the equation from Demir et al (2007) in the text so that the reader can understand the nature of the dependence on each variable.

Navy Follow-up Response: Equation from Demir et al (2007) has been included in Section 5.6.

3. PREQB Page-Specific Comment 9, Page 6-1, Section 6 – Summary and Conclusions: The conclusions in Section 6 of the report identify changes in beach morphology due to wave activity, but no discussion of how

the observed wave climate was related to the observed changes in beach cross section is provided in either the body of the report or the associated appendices. Please include a discussion in the revised report.

Navy Response: Please see the response to General Comment #2.

PREQB Evaluation of Response: As discussed above in association with PREQB General Comment 3, Tables 5-3 through 5-15 do not directly document how the collected data on wave activity, runoff, etc., were used to relate these processes to observed changes in beach cross section. Please include this information in the revised document.

Navy Follow-up Response: Please see the follow-up response to PREQB evaluation of General Comment #2.

APPENDIX-SPECIFIC COMMENTS

Appendix A (Wave Measurement) and Appendix I (Wave Analyses)

1. PREQB Comment 1: The wave data shown is limited to histograms of significant wave height, period, and direction as a function of season. In assessing the wave data, it would be useful and PREQB requests that time series plots of these variables, as well as representative energy and directional spectra for the three deployment sites, be provided in the revised report.

Navy Response: Time series plots of wave height, period and direction will be added. Wave spectra were not measured.

PREQB Evaluation of Response: The response is acceptable. The time series plots will be a welcome addition; however, please note that standard AWAC measurements should be able to provide calculation of frequency and directional spectra, which would be a valuable data set for inclusion in the revised document.

Navy Follow-up Response: Frequency and directional spectra are derived data from the AWAC raw measurements. Spectra data were processed but not included in the report because they are not relevant to the objectives of the BDI. Thousands of spectra were processed, one at every hour for the duration of the measurements (approximately 2 years) and for each of the three offshore locations. Because spectra data are a representation of the sea state, and sea states change with time and space, spectra also change and are all different. Generic site-specific spectra can be derived from the processed spectra, but this is not within the scope of the BDI nor necessary to the evaluation. However, upon request, the processed spectra data in ASCII files can be provided separately.

Appendix J (Beach Dynamics Results and Analysis)

1. PREQB Comment 2: In addition to the envelope of beach changes indicated on the figures, inclusion of the individual measured transects is requested. An understanding of the temporal evolution of the beach profile is important in identifying whether the observed changes occur gradually or episodically, and what mechanisms are forcing those changes.

Navy Response: The Beach Dynamics Investigation was conducted to evaluate the changes in beach profiles at each transect, thereby generating a good understanding of the evolution of the beach profile based on the numerous surveys conducted. Appendix J is intended to provide the highest and lowest elevations of the beach profiles, since each individual profile will be contained within all the other profiles. Significant findings related to the temporal evolution are summarized in Tables 5-3 through 5-13, as applicable. For instance, the seasonal shoreline position change at Beach 24 is summarized in Table 5-11. Inclusion of a figure for every measured transect would be unnecessary cumbersome for the report.

PREQB Evaluation of Response: The information presented in Tables 5-3 through 5-15 represents a summary and interpretation of the collected data, and this material is appropriate for the main body of the report; however, the appendices should include enough data to independently corroborate the conclusions

in the main body of the report. PREQB's intent is not to be unnecessarily cumbersome as the proposed change is anticipated to result in one additional panel for each transect. A suggestion is to define the first measured transect at each location as the "baseline" transect, and, for each additional measured transect, plot the difference between the measured elevation and the baseline elevation. In this manner, all transects are included on the same figure, and a quick inspection of the figure can identify whether the measured beach changes are gradual, episodic, or sporadic, in nature.

Navy Follow-up Response: While the requested information may be of interest, it is outside the scope of the BDI and not necessary to meet the BDI objectives (i.e., identifying maximum and minimum beach profiles). However, if the reader would like the raw data in order to perform the requested evaluation, they can be provided separately.

2. PREQB Comment 3: Discussion of the processes responsible for the observed changes is somewhat limited. To the degree feasible, please include a comparison of the profiles, coupled with an understanding of the wave climate from the wave measurements, to identify whether cross shore or along shore processes are responsible for the observed changes. This information would be valuable to the understanding of potential MEC migration.

Navy Response: Please see the response to General Comment #2.

PREQB Evaluation of Response: Consistent with previous responses provided herein, PREQB respectfully acknowledges that conclusions and interpretations are effectively summarized in Tables 5-3 through 5-15; however, sufficient data and/or analyses to corroborate those conclusions should be presented in the appendices. In this case, comparison of measured wave statistics to observed beach profile changes, both graphically and in the written discussion, would significantly enhance the report and the support of the conclusions.

Navy Follow-up Response: Please see the follow-up response to PREQB evaluation of General Comment #2.