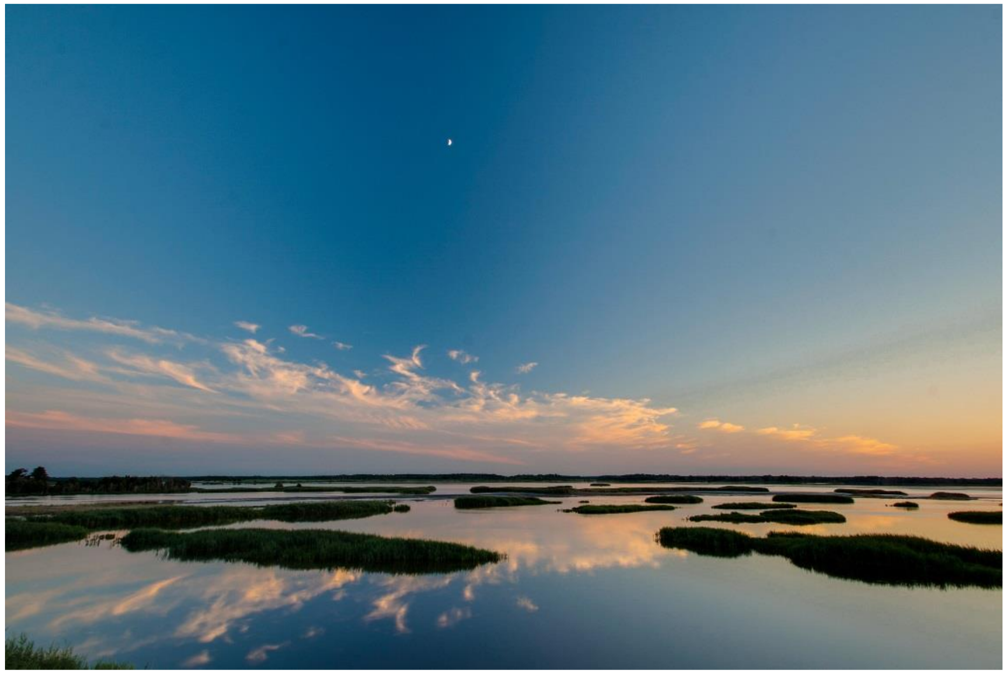

# Living Shorelines Assessment for Community Resiliency in Coastal Pennsylvania

## Final report for

## The Pennsylvania Sea Grant Program

Subaward No. 5416-DDE-NOAA-0063

Partnership for the DELAWARE ESTUARY

October 2018 | Report No.18-04

A publication of the Partnership for the Delaware Estuary—A National Estuary Program

# 1.0 Cover Page

Title: Living Shorelines Assessment for Community Resiliency in Coastal Pennsylvania: Final report for The Pennsylvania Sea Grant Program

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Project Period: February 1, 2016-September 30, 2018

Subaward No.: 5416-DDE-NOAA-0063

The Partnership for the Delaware Estuary brings together people, businesses, and governments to restore and protect the Delaware River and Bay. We are the only organization that focuses on the entire environment affecting the river and bay — beginning at Trenton, including the greater Philadelphia metropolitan area, and ending in Cape May, New Jersey and Lewes, Delaware. We focus on science, encourage collaboration, and implement programs that help restore the natural vitality of the river and bay, benefiting the plants, wildlife, people, and businesses that rely on a healthy estuary.

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## Acknowledgements

The authors are deeply grateful for the generous funding provided for this effort by the National Oceanic and Atmospheric Association through the Pennsylvania Sea Grant Program pass-through entity (PTE) Pennsylvania State University (PTE Federal Award Number: NA14OAR4170063), to the Partnership for the Delaware Estuary. We are also deeply grateful to the Philadelphia Water Department (PWD), particularly Lance Butler and Richard Anthes Jr, who provided logistical field support through boat transport, site evaluation, and bathymetric survey data which were essential to project completion. Several other PDE staff and students assisted with the field surveys and data processing, including Spencer Roberts and Sandra Demberger.

## Suggested Method for Citing this Report.

Moody, J., D. Kreeger, I. Beal, and S. Bouboulis. 2018. Living Shoreline Assessment for Community Resiliency in Coastal Pennsylvania. Partnership for the Delaware Estuary Final Report to the Pennsylvania Sea Grant Program. PDE Report No. 18-04. 60 p.

# Contents

# List of Figures

# List of Tables

# 2.0 Executive Summary

As sea levels rise, the people along Pennsylvania's eastern coastlines face many challenges, including the loss of tidal wetlands and the associated increase in coastal flooding (Nicholls 2004). Tidal wetlands remain a valuable buffer for rising seas levels and vital habitat for fish and wildlife (Beck et al. 2001; Knight 1997). Unfortunately, the Delaware Estuary in southeast Pennsylvania has lost >95% of its coastal marshes since colonial times (DEP 2015), and ecologically sound measures are needed to protect those that remain from erosion (horizontal loss) and/or drowning (vertical loss). Living shorelines represent an innovate measure to protect and enhance Pennsylvania's remaining coastal wetlands, and to restore these vital habitats at locations where they were once present. The goal of this study was to identify locations that were amenable to living shoreline implementation within the coastal zone of southeast Pennsylvania and to prepare initial conceptual designs for a subset of candidate living shoreline sites. Locations for conceptual designs were selected based on feasibility of implementation and adaptive management activities, as well as pre-existing physical and biological conditions.

A two-tiered rapid assessment methodology was developed to assess potential living shoreline locations and condition. First, a desktop-based GIS analysis was employed to identify sites that were situated on public land and were classified as having, or that once had, emergent wetland land cover. A subset of the sites that were accessible and aligned with stakeholder priorities were selected for rapid *in situ* site assessment. A living shoreline feasibility model was developed to integrate historic trajectory, biological and physical condition, and community value, as represented through public access and educational outreach potential, metrics which were assessed at each site. Model output was used to identify site-specific goals and trajectory drivers, allowing for the selection of the appropriate living shoreline tactic at each site. The highest ranking sites were subsequently revisited for further topographic and bathymetric data collection for the development of site-specific conceptual designs.

Conceptual designs were developed for the Bartram's Garden, Windy Point, and Paine's Park sites. Attainable goals for Bartram's Garden and Paine's Park were deemed to be habitat and water quality uplift (as well as outreach). The design for both sites focused on shallow subtidal mussel pens to attenuate energy waterward of the existing shoreline, and to provide water quality uplift through the filtration of the resident bivalve population. At Windy Point, the primary goal was erosion control. Low and high marsh communities in compartmentalized locations along the existing shoreline would increase habitat values and buffer against erosion. It is important to note that before these designs can be implemented, more refined data collection is necessary to confirm modeled elevation profiles and test geotechnical support of the substrate. This study showed the value of an integrated desktop and field-based methodology to identify and prioritize potential living shoreline site locations. Further, the development of a rapid assessment living shoreline feasibility model will allow for additional sites to be evaluated in an identical manner for continued site identification and prioritization along Pennsylvania's coastal margins.

# 3.0 Introduction

Sea level rise presents numerous challenges for preserving critical natural habitats and protecting people along the Pennsylvania coastline (DEP 2015). Chief among these is the potential loss of tidal wetlands to rising seas (Kirwan and Megonigal 2013). Tidal wetlands are the most valuable natural habitats because they buffer waves and storm surge (Temmerman et al. 2013), remove pollutants and nutrients (Jordan et al. 2003; Sun et al. 2005), sequester carbon (Mcleod et al. 2011), and they furnish vital habitat for fish and wildlife (Beck et al. 2001; Knight 1997). Unfortunately, southeast Pennsylvania has lost >95% of its coastal marshes and the percentage losses continue to be the greatest in the system (DEP 2015). This trend is worrisome considering that coastal wetlands are vital for climate adaptation.

Adaptation to sea level rise, for example, includes "horizontal" measures to move vulnerable structures and communities landward and "vertical" measures that elevate or protect vulnerable structures, communities, or natural habitats. For this latter category, protection and elevation options are diverse and include "hard" tactics such as building seawalls, bulkheads, dikes, and tidal control systems, as well as filling lands to elevate them. However, hard structures typically degrade wetlands and stream bank areas and the ecological goods and services they provide. "Soft" tactics such as living shorelines are an alternative that promotes natural habitats which can provide similar protection or elevation without degrading ecosystem goods and services. In 2008, the Partnership for the Delaware Estuary (PDE) implemented the Delaware Estuary Living Shoreline Initiative (DELSI) as a method to implement living shorelines at strategic locations of community importance in need of structural and ecological support. Between 2008 and 2016, PDE has installed and monitored 14 living shorelines at seven locations in the brackish portion of the Delaware Estuary, and has recently been involved in the planning of four living shorelines in the tidal, freshwater portion. To date though, no living shorelines have been installed in the upper portion of the Delaware Estuary where ecological conditions are dominated by freshwater tidal organisms.

The Partnership for the Delaware Estuary is seeking to protect Pennsylvania's natural shoreline habitats and coastal communities from the threats associated with rising sea levels and climate change through the implementation of living shoreline efforts along the freshwater urban corridor of the estuary. The first step in a strategic and scientific approach to living shorelines planning and installation is the assessments and prioritization of possible sites within the study area. The results of these studies can then be used to justify and secure funding from government, private and corporate sources for on-the-ground living shoreline installations.

# 4.0 Methodology

## Approach

The goal of this effort was to identify locations along the tidal Delaware and Schuylkill Rivers in Pennsylvania that were suitable for a living shoreline approach to increase coastal resiliency and ecological integrity, thereby helping to protect coastal communities from climate change. The overall approach of this project was a science-based evaluation method to identify parcels of publicly owned land appropriate for wetland restoration where a living shoreline method was feasible to deploy and likely to persist. The specific objectives of this project were as follows:

1) Identify publicly owned parcels of land classified as locations where wetlands are currently or were recently located;
2) Use a rapid assessment methodology *in situ* to gather information regarding the physical, biological, accessibility, and outreach potential at each previously identified site;
3) Develop a living shoreline feasibility model to identify each site's primary concern and its driver(s);
4) Use the feasibility model to screen the previously identified sites using each site's unique data set and rank them in terms of their ease of implementation and likelihood of persistence; and
5) Develop conceptual designs for the top three identified sites that address the sites' primary goals and main drivers.

# Methods and Results

Areas of interest were selected for field reconnaissance through GIS analysis to pinpoint appropriate areas based on energy conditions, land ownership and accessibility, erosion conditions, and community/decision maker outreach opportunities. These areas were then narrowed down through field assessments to measure energy, hydrodynamic and other abiotic factors, assess baseline biotic conditions, and confirm suitability for living shoreline pilots. The top three prioritized sites where planning efforts were not already currently underway were identified to:

1) be the most suitable for living shoreline installation and persistence;

2) benefit from increased ecosystem services provided by the living shoreline; and

3) serve as demonstration sites to show the importance of protecting and enhancing shorelines.

# GIS-Based Site Selection

A GIS desktop-based approach was used to identify potential living shoreline sites that were:

1) located within 50m of the delineated shorelines of the Delaware or Schuylkill Rivers, within Philadelphia County;
2) located on public land; and
3) categorized as having wetland vegetation as the dominant vegetation type.

Data sets used for identifying land use (public lands) were created by Mark Wheeler, GISP, part the City of Philadelphia's GIS division. Parcels coded as "civic/institution," "transportation," "culture/recreation," and "park/open space" were selected in the analysis as they were all likely to be publicly owned properties. The land cover dataset was developed by the University of Vermont Spatial Analysis Laboratory and Shippensburg University as part of their Delaware River Basin Land Use Dynamics, Delaware River Basin Project. Parcels coded as "wetlands" or "low vegetation" were selected for the analysis as vegetation types of interest. An intersection of the land use and land cover data ("public lands" & "wetlands") was created for Philadelphia County. A shoreline buffer of 50m was created on both the Delaware and Schuylkill rivers. This buffer was then intersected with the land use/land cover data to create a final "parcels of interest" data layer. The resulting dataset included several thousand parcels to be narrowed for *in situ* visitation.

Through personal communication with Dr. Danielle Kreeger of the Partnership for the Delaware Estuary (PDE) and Lance Butler of Philadelphia Water Department (PWD), a smaller subset of the candidate sites was then selected as the primary areas of interest using best scientific judgement and historical knowledge of the locations. These areas were subsequently overlaid on the GIS suitability assessment to confirm proper land use and land cover, and evaluated using satellite imagery for ease-of-access and suitability (i.e., was not already industrialized, fenced-off, in development, or heavily armored). From this subset, 26 suitable sites were identified for potential field-based assessments (Table 1, Figure 1). Subsequent site visitation revealed that only 13 of the sites were able to be accessed for field-based assessment due to access restrictions (gating) or safety considerations such as terrain-related obstacles (Figure 2).

*Table 1. Twenty-six sites initially identified by GIS land use and land cover analysis and narrowed through personal communications*

| Site ID | Northing | Easting | Land Use | Land Cover | Ownership | Boat or Land Access |
|---|---|---|---|---|---|---|
| **DR01** | 40.0509 | -74.9786 | Culture | Low Vegetation | Glen Foerd on the Delaware | Land |
| **DR02** | 40.0438 | -74.9873 | Park/OpenSpace | Low Vegetation | Delaire Landing | Land |
| **DR03** | 40.0423 | -74.9904 | Park/OpenSpace | Low Vegetation | Pleasant Hill Park/Fish Hatchery | Land |
| **DR04** | 40.0399 | -74.9927 | Park/OpenSpace | Low Vegetation | Pleasant Hill Park/Fish Hatchery | Land |
| **DR05** | 40.0345 | -74.9993 | Water | Low Vegetation | Philadelphia Fire Academy | Land |
| **DR06** | 40.0303 | -75.006 | Water | Low Vegetation | Pennypack Park | Boat |
| **DR07** | 40.0263 | -75.0132 | Water | Low Vegetation | Pennypack Park | Land |
| **DR08** | 40.0197 | -75.033 | Culture | Low Vegetation | Quaker City Yacht Club? Tacony Boat Launch | Land |
| **DR09** | 40.0149 | -75.0456 | Transportation | Low Vegetation | Lardner's Point Park/PennDOT | Land |

| | | | | | | |
|---|---|---|---|---|---|---|
| **DR10** | 40.0127 | -75.0484 | Park/OpenSpace | Low Vegetation | Lardner's Point Park | Land |
| **DR11** | 40.007 | -75.0564 | Culture | Low Vegetation | Frankford Boat Launch | Land |
| **DR12** | 39.9941 | -75.0643 | Culture | Low Vegetation | Bridesburg Outboard Club | Land |
| **DR13** | 39.9653 | -75.1289 | Water | Low Vegetation | Penn Treaty Park | Land |
| **DR14** | 39.9264 | -75.1403 | Water | Low Vegetation | Pier 68, DRWC | Land |
| **DR15** | 39.8949 | -75.1399 | Transportation | Low Vegetation | Windy Point, transportation | Boat |
| **SR01** | 39.9914 | -75.1995 | Park/OpenSpace | Low Vegetation | Schuylkill River Trail | Land |
| **SR03** | 39.9759 | -75.1926 | Park/OpenSpace | Low Vegetation | Schuylkill River Trail/Fairmount Park | Land |
| **SR04** | 39.9629 | -75.1813 | Park/OpenSpace | Low Vegetation | Fairmount water works, River Trail, Paine's Park | Land |
| **SR05** | 39.9508 | -75.1816 | Park/OpenSpace | Low Vegetation | Schuylkill River Trail/Schuylkill Banks | Boat |
| **SR06** | 39.9429 | -75.1958 | Transportation | Low Vegetation | University of Pennsylvania | Boat |
| **SR07** | 39.9433 | -75.2016 | Park/OpenSpace | Low Vegetation | Grays Ferry/Dupont Crescent Trail Park | Boat |
| **SR08** | 39.9334 | -75.2087 | Park/OpenSpace | Low Vegetation | Bartram's Garden | Land |

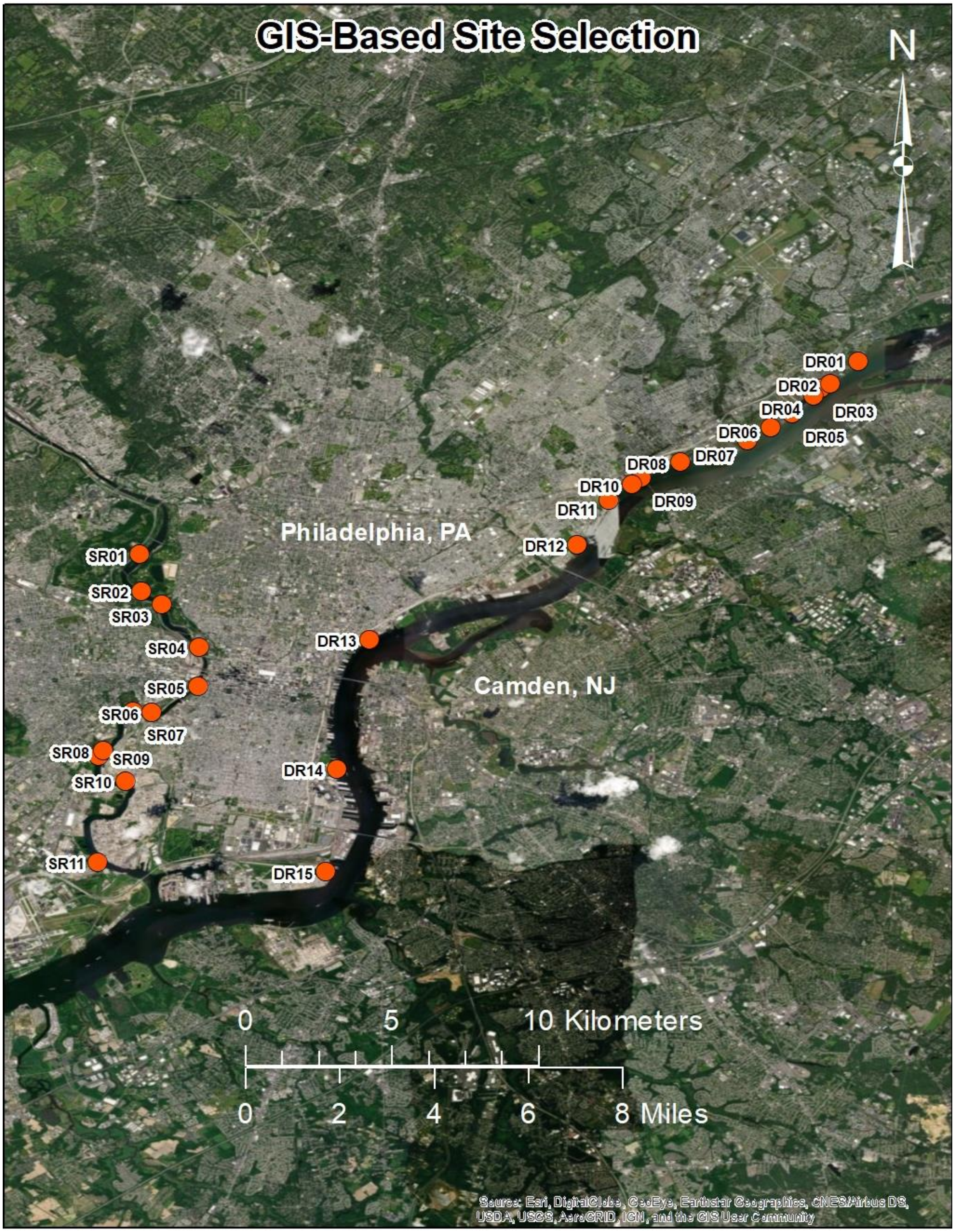


*Figure 1. Locations of 26 sites initially identified for site visitation,*

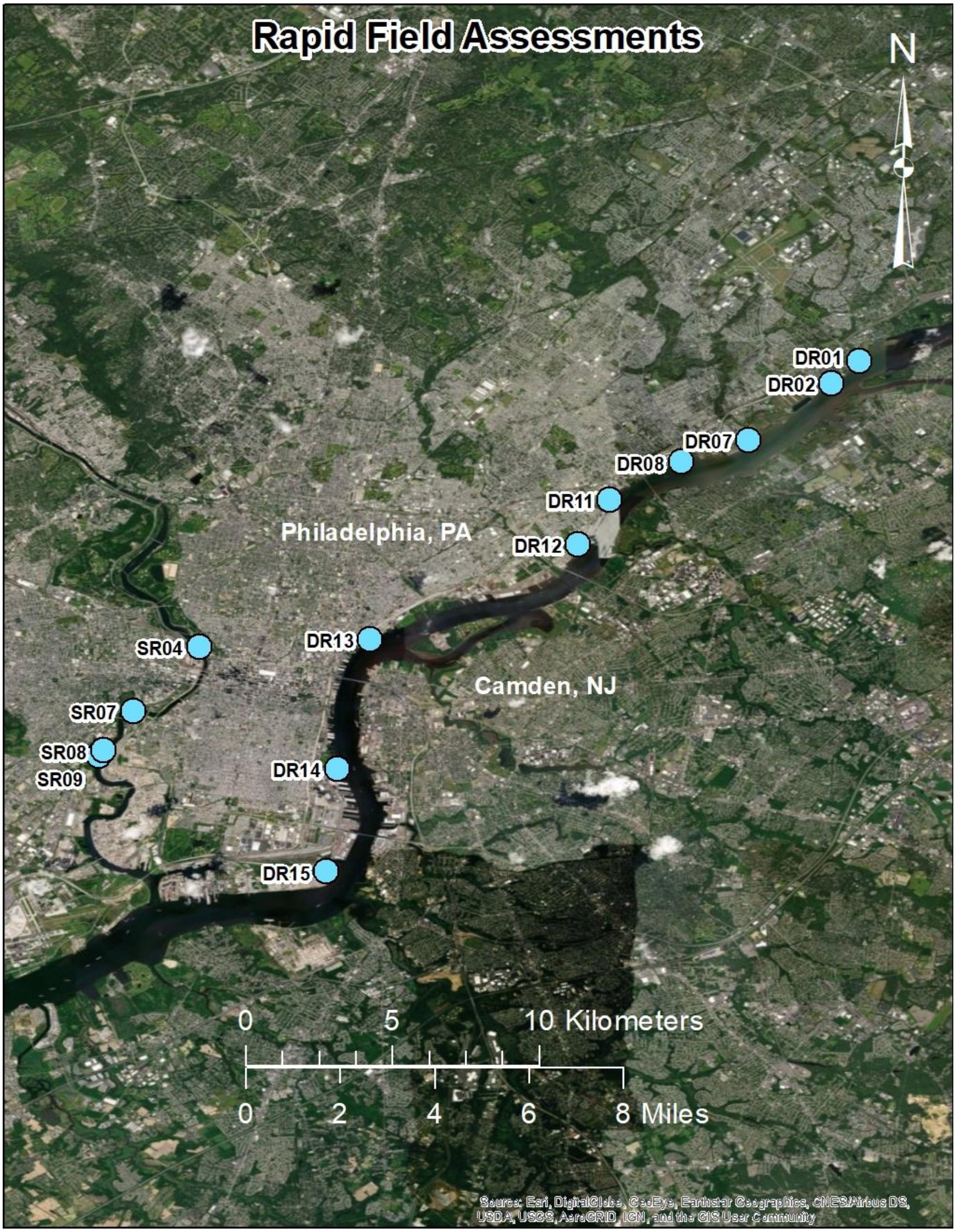


*Figure 2.Locations of the 13 sites that were evaluated* in situ.

# Site Feasibility Model Development

A living shoreline feasibility model was developed to integrate field-based data from the site visits to assess ease of installation and likely persistence of a living shoreline at a particular location. Feasibility was assessed based on five primary parameters: Site Trajectory; Physical Characteristics; Biological Characteristics; Accessibility; and Community Potential. The score for each primary parameter was calculated based on the valuation of a subset of metrics (Figure 3) described below. Data were collected for all metrics at each of the 13 sites, and feasibility scores were calculated using the following formula:

Site Trajectory * [Physical Characteristics + Biological Characteristics + Access + Community Engagement]

## Model Parameters and Metrics

**Site Trajectory (Range 0 to 1):** This parameter describes the trajectory of lateral shoreline change over time. The following criteria were scored as such: A landward migration (erosion) of the boundary between the intertidal and upland area (+1), no net change (+1), and waterward migration (accretion) (0). This factor either kept the site in the competitive rankings among the other sites (*1), or it removed the site from consideration by dropping the score to 0 (*0).

**Physical Characteristics (Range -10 to 0):** This parameter describes the main physical drivers that dictate whether a site may be suitable for a living shoreline, including whether there was a historic structure to attenuate wave impacts with structural materials. Physical Characteristic metrics include: condition, fetch, slope, and marina proximity—below parameters are summed for total Physical Characteristics score.

<u>Condition (Range -5 to 0):</u> This metric scored the presence of any existing hard or soft features and was assessed observationally. Scoring was as follows: Presence of seawalls or breakwaters (-5), presence of riprap or stone (-3), historic infrastructure such as piling or piers (-1), or a natural landscape (0).

<u>Fetch (Range -2 to 0):</u> This metric scored the distance of water adjacent to the site over which wind is able to generate waves, and was assessed using desktop software (e.g. Google Earth-used in this study, Google Maps, ArcGIS, etc.). Fetch distance was measured by averaging the distance across the adjacent body of water in 5 equally spaced directions from center point of site (adapted from Steven's Institute Living Shoreline Engineering Guidelines). Scoring was as follows: Low (<1 mi) (0), Medium (1-5 mi) (-1), or High (>5 mi) (-2).

<u>Slope (Range -2 to 0):</u> This metric scored the average slope of the intertidal area of the site between mean low water and the upland boundary. Slope was assessed using survey RTK-GPS measurements along three transects oriented perpendicular to the shoreline. Although this high rigor method was used for this study, other, less intensive methods that do not require specialized equipment and/or software can be employed (e.g. laser level). Scoring was as follows: Low (<10%) (0), Medium (10-20%) (-1), High (>20%) (-2).

<u>Marina (Range -1 to 0):</u> This metric scored the presence (-1) or absence (0) of a marina in close proximity of the site, and was assessed observationally.

**Biological (Range -3 to +3)**: This parameter describes the current biological conditions at the site, specifically the plant and animal communities and dominant species, as well as the existing substrate types. Biological Characteristic metrics include: existing habitat potential and shellfish presence.

<u>Existing Habitat Potential (Range -3 to +2):</u> This metric scored the pre-existing biological and substrate

conditions, and was assessed observationally. Scoring was as follows: Barren, no soft sediment/sand or vegetation present on site (-3), Either soft sediment/sand or vegetation present (0), or sediment/sand and vegetation present (+2).

Shellfish Presence (Range 0 to +1): This metric scored the presence (+1) or absence (0) of sessile shellfish (e.g., bivalve mollusks) on the site, and was assessed observationally. Shellfish were specifically chosen as a metric due to their foundational capacity as ecosystem engineers. Shellfish help to build habitat colonized by other organisms (e.g. within interstitial space between shells, as refuge of nursery fish, etc.) and also provide physical stabilization of sediments and attenuation of energy.

**Accessibility (Range -2 to 0):** This parameter describes the accessibility of the site for both installation/adaptive management needs and for community interaction with the installation.

Maintenance Accessibility (-1 to 0): This metric scored the ease of material delivery and assessment visits by either land or water, and was assessed observationally. Scoring was as follows: Low -difficult by boat: distance, sub-tidal structures, restricted boat access (-1), Medium -easy by boat or access by land with some difficulty (e.g., distance, terrain; -0.5), or High- direct land access with easy terrain (0).

Human Disturbance (-1 to 0): This metric scored the accessibility of the installation materials to the general public for use (e.g. fishing, picnicking, dumping, etc…), and was assessed observationally. Scoring was as follows: Low (0), Medium (-0.5), or High (-1).

**Community Engagement Potential (Range 0 to +5):** This parameter describes the potential of the site as an opportunity to engage with the community and/or serve as an educational focal point.

Educational Opportunity (Range 0 to +2): This metric scored included presence (+2) or absence (0) of either installed or natural features (e.g., shellfish, plant species, macro invertebrates, stream convergence, natural landscape in urban area, etc…) that would provide opportunity for educational activities. This metric was assessed observationally.

Public Viewing (Range 0 to +3): This metric scored the presence (+3) or absence (0) of an area for clear viewing of the living shoreline or where signage could be installed, and was assessed observationally.

| | |
|---|---|
| **Shoreline Trajectory** | |
| Landward Migration | 1 |
| No Net Change | 1 |
| Waterward Migration | 0 |
| **Physical** | |
| Condition | |
| Seawall/Breakwater | -5 |
| Rip-Rap/Stone | -3 |
| Historic Infrastructure | -1 |
| Natural Landscape | 0 |
| Fetch | |
| Low ( <1 mi) | 0 |
| Medium (1-5 mi) | -1 |
| High ( >5 mi) | -2 |
| Slope | |
| Low ( <10%) | 0 |
| Medium (10-20%) | -1 |
| High ( >20%) | -2 |
| Marina Proximity | |
| No | 0 |
| Yes | -1 |

| | |
|---|---|
| **Biological** | |
| Existing Habitat Potential | |
| Barren Site | -3 |
| Sediments OR Plants on Site | 0 |
| Sediments AND Plants on Site | +2 |
| Shellfish Presence | |
| No | 0 |
| Yes | +1 |
| **Accessibility** | |
| Maintenance Accessibility | |
| Low | -1 |
| Medium | -0.5 |
| High | 0 |
| Human Disturbance | |
| Low | 0 |
| Medium | -0.5 |
| High | -1 |
| **Community Engagement Potential** | |
| Educational Opportunity | |
| No | 0 |
| Yes | +2 |
| Public Viewing | |
| No | 0 |
| Yes | +3 |

*Figure 3. Model parameter scoring values (bold) and per-metric valuation (light). Metrics are underlined beneath their associated parameter and scoring value factor levels per metric are subsequently listed.*

# Rapid Field Assessments

The 13 sites that were accessible by boat or foot were evaluated *in situ* during brief (~1hr) site visits. Although some specialized equipment was used (i.e. Trimble R6 RTK-GPS) all metrics are able to be assessed via observation or low rigor methodologies (e.g., Google Earth, Google$^{TM}$ Maps, etc.). Below are descriptions of the conditions that were observed at each of the sites and potential project goals. Scores for all metrics and parameters, as well as rankings for model output are described in the following section and are summarized in Table 2.

## Bartram's Garden (SR-08&09)

Bartram's Garden (39.9334, -75.2087) is the oldest surviving botanic garden in North America. Located on the west bank of the Schuylkill River, it covers 46 acres and includes an historic botanical garden and arboretum. The shoreline along the Schuylkill River had been experiencing erosion that was encroaching onto the grounds of the Gardens, but is currently stable. The low energy and high biological potential at this site made this an ideal location for bio-based living shorelines to stabilize the land-water interface and to enhance biota such as intertidal wetlands, submerged aquatic vegetation, and beds of freshwater mussels. Water quality could potentially be improved with an increase in intertidal vegetation from sediment sequestration and particle/nutrient removal via filter-feeding shellfish. Additionally, the high visibility and current on-site educational programming provides significant outreach opportunities. Remnant infrastructure (e.g. old piling and dock materials) would provide ideal anchoring sites for vegetation terracing. Goals for a living shoreline installation at this location would include erosion control and habitat, both sub-(freshwater mussel) and intertidal (vegetation) enhancement.

*Figure 4. SR-08 & 09 Bartram's Garden potential living shoreline site.*

## Bridesburg Outboard Club (DR-12)

Bridesburg Outboard Club (39.9941, -75.0643) is located in the Bridesburg neighborhood of North Philadelphia south of Bridesburg Channel. The medium energetics and pre-existing intertidal and submerged aquatic vegetation would help support waterfowl and freshwater mussels. The site would benefit from enhanced water quality and habitat uplift via the installation of self-sufficient communities of intertidal vegetation and freshwater mussels. Site accessibility was low due to steep slopes and the possibility of privately owned land due to the presence of a nearby boat club.

A retaining wall to the north and rip-rap to the south armor the intertidal area, potentially resulting in a high level of reflective energy across the site. Pre-existing flora include a mono culture of intertidal *Nuphar lutea* and submerged aquatic vegetation. Potential fauna usage includes waterfowl, other birds, mammals, and freshwater mussels. Some freshwater mussels (*Elliptio complanata, Utterbackiana implicata*, and *Ligumia nasuta*) were observed during the visit. Human disturbance of the area is low with a private boat ramp and marina/boat launch site nearby. The intertidal substrate consists of small rocks/pebbles, pluff mud, and firm mud. The fetch in this area is 0.85 miles. Since 1996, the vegetated edge has progressed landward. Goals for this site would be to enhance water quality and habitat through the introduction of upland plants, wetland plants, and mussels.

*Figure 5. Bridesburg Outboard Club looking west at a cobble and mud substrate with upland vegetation and Nuphar*

## Windy Point (DR-15)

Windy Point (39.8949, -75.1399) is located south of the Walt Whitman Bridge along the Delaware River in an area removed from public view. This area is eroding despite sections being heavily armored. Nearby shipping activity has caused significant wake energy and the armoring along the site borders has resulted in enhanced energetics along the site. Unfortunately, the site currently suffers from poor condition likely dues to the reflective energy preventing the expansion of the extant biological community. The medium energetics and high biological value currently at the site made it a prime candidate for potential freshwater mussel and intertidal marsh habitat enhancement. Although removed from direct public viewing and outreach engagement opportunities, a living shoreline at this site would prove to be ideal for the restoration and expansion of mussel habitat for improved water quality uplift via enhanced filtration capacity. Potential living shoreline goals at this site would be erosion control and enhancement of current ecological conditions.

*Figure 6. DR-15 Windy Point potential living shoreline site*

## Paine's Park (SR-04)

Paine's Park (39.9629, -75.1813) is located on the Schuylkill River, just off the Schuylkill Trail below the Eakins's Oval on the Ben Franklin Parkway. Currently, there is adequate shallow intertidal area and the bank has not been structurally armored. The presence of pluff mud, sand, and pebbles support the conclusion that along-site energetics have been typically low, but the presence of multiple stormwater outfalls with established gullies, one of which has a scour pool; and close proximity to the dam at the Fairmount Waterworks do allow for potential periodic high flow velocity scenarios. Although biological condition was low on-site, the low energy and high public visibility afford this site high potential as an important outreach location for education regarding urban living shorelines. The soft sediment interspersed with pebble substrate may provide ideal habit for a freshwater mussel community that would filter a large volume of water, thus improving its quality. A primary goal for a living shoreline installation would be habitat enhancement of freshwater mussel and intertidal vegetation communities.

*Figure 7. SR-04 Paine's Park potential living shoreline site*

## Penn Treaty Park (DR-13)

Penn Treaty Park (39.9653, -75.1289) is located in the Fishtown neighborhood of Philadelphia along the Delaware River. This site is easily accessible and shows signs of frequent use. A larger fetch (1.81 miles) was measured at the site, and as such it has been armored using rip rap to protect the adjacent park from shoreline erosion. A sparse biological community was present along the site with no vegetation or animal presence observed, although a large expansive mudflat may be suitable for vegetation plantings. Potential goals for a living shoreline at this site includes habitat restoration through intertidal vegetation plantings and an introduction of freshwater mussels could improve water quality. Its location adjacent to the park would be ideal for community outreach and future education programs. Sources outside the project team indicated that restoration planning activities had already been initiated at this location.

*Figure 8. Penn Treaty Park looking north at a hardened shoreline with boulders and a mudflat out front with no wetland vegetation.*

## Maggie’s Restaurant (DR-02)

Maggie’s Restaurant (40.0438, -74.9873) is located in the Torresdale neighborhood in Northeast Philadelphia along the Delaware River. This site was characterized by a barren landscape, but direct public access and outreach opportunities. Although the high energetics and lack of foundational biological community may be challenges, the low slope and position between two laterally protective piers make this site ideal for a hybrid living shoreline. The location of this site would provide a great deal of opportunity to engage the public regarding the potential habitat uplift from natural infrastructure. Potential living shoreline goals at this site include habitat enhancement of inter- and subtidal flora and fauna.

*Figure 9. Maggie’s restaurant looking south at a bulkheaded shoreline and a cobble and sand beach*

## Grays Ferry Crescent Trail Park (SR-07)

Grays Ferry Crescent Trail Park (39.9433, -75.2016) is located north of Grays Ferry along the Schuylkill River. There was slight upland erosion despite artificial stabilization from bricks along the shoreline. The substrate offshore was mostly firm and sandy. This low-energy environment could support intertidal vegetation and possibly freshwater mussels, both of which would improve water quality and ecological uplift. Its proximity to a public park could provide educational outreach opportunities depending on success of the project. Potential living shoreline goals for this site include the habitat enhancement of the inter- and subtidal flora and fauna.

*Figure 10. Grays Ferry Crescent Trail Park looking north at a low-energy environment and a sand and cobble beach*

## Pier 68 (DR-14)

Pier 68 (39.9264, -75.1403) is owned by the Delaware River Waterfront Corporation (DRWC) and is located to the east of Pennsport, Philadelphia along the Delaware River. The site is inaccessible except by boat and the bulkheaded perimeter has resulted in low flora presence along the site. Additionally, the substrate was comprised of deep, soft mud that may compromise the geotechnical stability of materials intended to augment the elevation profiles. Restoration activities at this site would require a high degree of engineering and redistribution of on-site materials. Upland plants were present but dense, and currently prohibitive for education and outreach opportunities. Ecological uplift, habitat variability, and educational outreach are potential living shoreline goals at this site.

*Figure 11. North of Pier 68 showing bulkheaded shorelines and lack of an exposed shoreline*

## Pennypack Park (DR-07)

Pennypack Park (40.0263, -75.0132) is located east of the Holmesburg Philadelphia neighborhood and south of Pennypack Creek. The shoreline along this site has been retreating since 1996 and the current rip rapped edge was in a state of disrepair. The presence of rip rap and lack of fine sediments was indicative of the high energy along the site. Although high energetics and low biologic integrity would serve as obstacles to establishing a robust vegetation community, the location in a public park with a high level of access would provide great outreach potential. To intercept the energy and provide refuge for an introduced biological community a hybrid living shoreline approach would be recommended. Potential living shoreline goals for this site include erosion control and habitat enhancement for both sub- and intertidal communities.

*Figure 12. Pennypack Park looking west at a low-energy cove bounded by rip-rapped, moderately sloped banks*

## Frankford Boat Launch (DR-11)

Frankford Boat Launch (40.007, -75.0564) is located south of the Tacony-Palmyra Bridge and north of Bridesburg Channel in the Wissinoming neighborhood of Philadelphia along the Delaware River. The beach and offshore were comprised of small and large rocks, sand, and firm mud. The shoreline to the south was bulkheaded with a tidal flat along the waterward margin. Construction accessibility is medium, but it has a high level of human disturbance potential. This area is already heavily used for fishing and boating. A living shoreline in this area may interfere with these current activities. The goal for this site would be habitat restoration and enhancement by adding wetland vegetation and possibly freshwater mussels.

*Figure 13. Frankford Boat Launch looking east at a moderately sloped, coarse and sand gravel beach with firm mud offshore*

## Tacony Boat Launch (DR-08)

Tacony Boat Launch (40.0197, -75.033) is located north of the Tacony-Palmyra Bridge in Northeast Philadelphia along the Delaware River. The shoreline at this site was comprised of boulders, stones, and with no sediment/sand present. Additionally, no inter- or subtidal vegetation was observed. Its proximity to the boat launch would likely result in high periodic energy increases as well as public disturbance. Potential living shoreline goals for this site include habitat enhancement as well community engagement due to its public location.

*Figure 14. Tacony Boat Launch looking east at a low sloped gravel beach*

## Glen Foerd on the Delaware (DR-01)

Glen Foerd on the Delaware, a riverfront estate, (40.0509, -74.9786) is located in Northeast Philadelphia along the Delaware River south of Poquessing Creek. There is some evidence of shoreline retreat since 1996 although it appears to be currently stable due to a rip-rapped shoreline and evidence of an old stone retaining wall. The retaining wall is in a state of disrepair at some locations, and a nature-based approach to shoreline stabilization would be appropriate when restoration of the area occurs. Some upland and wetland plants were present on site, but no mussels were observed. Public viewing potential is high if amendments were made to the site, but access was by foot and was difficult during the site visit. Restoration access is high by boat, but unless the hillside was regraded, there was little room for staging of materials during living shoreline installation. Potential living shoreline goals include stabilization of the historic retaining wall via natural buffers that would improve both habitat and erosion control.

*Figure 15. Glen Foerd on the Delaware north of the gazebo looking at a hardened shoreline with rip rap and an old retaining wall*

# Living Shoreline Feasibility Model Output

The feasibility model calculated categorical scores based on the sub-categorical metrics each site received an initial score of 15 that was adjusted by the metric scores. The model output was discussed with partners, and four sites (one in the Delaware River (DR) and three in the Schuylkill River (SR)) were selected for conceptual design development. Model output can be evaluated in three fashions:

1. Absolute Overall Ranking: The final score values for sites raking higher than other values are interpreted as having a greater overall feasibility for living shoreline applications. Overall ranking is useful for user groups that have high levels of comprehensive experience across all parameters, and can also be used to identify the experiential needs of the final design and implementation team.
2. Conditional Subset Ranking: A subset of sites is selected and subsequently ranked by final score based on particular needs of the selection group. For example, a user may be only interested in sites that are located in areas with high public visibility. In that case, only the subset of sites that scored a "3" for the public viewing metric would be selected and subsequently ranked for site selection. This form of subset ranking is useful for user groups that have particular missions associated with a subset of parameters.
3. Opportunistic Subset Ranking: A subset of sites is selected and subsequently ranked by final score based on relative levels of site-specific drivers. For example, a user with a high level of experience regarding energy attenuation and less experience in biological community building may not be deterred from a particular site due to low Physical scores, but may prefer to avoid sites with low Biological scores. This form of subset ranking is useful for user groups that have high levels of experience with one or two parameters, and low levels of experience with others.

Absolute overall ranking was the chosen evaluation method for this study, and as such, all sites were considered based on their final rankings. The goal of the modeling effort was to select three sites that showed the greatest living shoreline feasibility and to compose conceptual designs of each of those sites. Results for the sites not chosen for conceptual design were cataloged and are available for consideration for future use.

The Bartram's garden sites (SR-08 & 09) were characteristically similar, and due to proximity along the shoreline, were grouped and considered as a single, albeit larger, site. Bartram's Garden had the highest overall feasibility ranking, scoring eight points higher than the second site, Bridesberg Outboard Club (DR 12; Table 2). Bartram's Garden showed low energetic concerns and high biological potential, with both suitable substrate and a minimal plant community already existing at the site. Additionally, low disturbance and good access complimented high community and educational opportunities. The combination of these metric scores identified Bartram's Garden as being a highly feasible site living shoreline applications. The primary goals at this site were found to be habitat enhancement for flora and faunal communities across the inter and shallow subtidal areas, as well as the associated water quality uplift that can be provided by an enhanced freshwater mussel community incorporated into the living shoreline design (Table3, Figure 16).

Although Bridesburg Outboard Club (DR-12), scored well for many of the same metrics as Bartram's Garden (Table 2), the high energetics due to the on-site marina posed a serious challenge. The site itself was located on publicly owned land, but all land-based access to the site was only achievable through the club's property. All other access points were impeded by fencing. Interviews with workers at the marina indicated that regular access would be a concern, and it was surmised that the gated, secure nature of the marina would require substantial planning and logistical coordination for land-based installation and maintenance. Although the site was accessible by boat, boat-based efforts require considerably more resources to transport materials and for logistics. For these reasons, this site was removed from consideration for this study, but the feasibility of the living shoreline approach at this location was ranked high. As other opportunities present themselves in this area, future considerations may warrant additional analyses.

Model scores for Windy Point (DR-15) and Paine's Park (SR-04) were identical (Table 2). Windy Point displayed poor conditions, likely because of its position between a pier and upland parking lot. However, this site did have an established emergent vegetation community and suitable substrate. The high biological potential serves as an example of a potential "proactive" living shoreline. Living shorelines are not only needed to protect and enhance areas that are already significantly degraded, but also to provide refuge and support to sites in the initial stages of degradation. Access was a concern, as land-access was constrained by a large, locked municipal parking lot. Windy Point was identified as a feasible site living shoreline applications (Table 2). The primary goal at this site was identified to be erosion control, to be achieved through the installation energy attenuation devices along the shallow intertidal to promote vegetation expansion in their lee. (Table3, Figure 16).

The primary challenge at Paine's Park was the current human disturbance level as well as difficulty of access through the steep and dense upland vegetation bordering the site along the landward margin. Although the biological potential at Paine's Park was lower than at Windy Point (Table 2), Paine's Park did have suitable substrate to support a biological community and good conditions along the intertidal area. Potential outreach opportunities and high visibility were identified as primary factors contributing to the site's advancement as a feasible location for a living shoreline effort (Table 2). The primary goals at this site were found to be habitat enhancement for flora and faunal communities across the inter and shallow subtidal areas, as well as the associated water quality uplift that can be provided by an enhanced freshwater mussel community incorporated into the living shoreline design (Table 3, Figure 16)

The group of sites consisting of Penn Treaty Park (DR-13), Maggie's Restaurant (DR-02), Grey's Ferry Crescent Trail Park (SR-07), and Pier 68 (DR-14), all scored low for the Physical parameter (high energetics and poor condition) and moderate for biological potential (Table 2). The combination of these parameter scores indicate that the biological potential of each site is likely stunted by either the high energy, or the current condition, and that modifications to the physical regime through the incorporation of energetic attenuation devices that would help to also trap sediment would provide biological refugia and condition to promote further ecological uplift. These sites were not selected for conceptual design.

The group of sites that includes Pennypack Park (DR-07), Frankfort Boat Launch (DR-11), Tacony Boat Launch (DR-08), and Glenn Foerd on the Delaware (DR-01) all scored low for both the Physical and Biological parameters (Table 2). High energetics and low condition were present at these sites, especially when the sites were in close proximity to marinas. All sites show poor biological potential, and were currently without an extant vegetation population or the substrate suitable for establishment. These conditions result in the need for a full ecological retrofit of the site. Substrate remediation would likely be the first step at all sites, followed by the introduction of appropriate plant species. Ecological establishment is a process that requires careful attention in the preliminary phases, and as such is an intensive process. These sites were not selected for concept design under this funding, although most of the sites, with the possible exception of Glen Foerd on the Delaware which may need more structural support, could benefit from a green infrastructure approach.

*Table 2. Output from the site feasibility model. Categories and parameters are ordered as presented in the text. Values represent the actual metric scores for each site collected during site visits.*

| Site | SR08 & SR09 | DR12 | DR15 | SR04 | DR13 | DR02 | SR07 | DR14 | DR07 | DR11 | DR08 | DR01 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Initial Score** | **15** | **15** | **15** | **15** | **15** | **15** | **15** | **15** | **15** | **15** | **15** | **15** |
| Condition | 0 | -1 | -3 | 0 | -3 | -5 | -3 | -5 | -3 | -3 | -3 | -5 |
| Fetch | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Slope | 0 | 0 | 0 | -1 | -1 | 0 | 0 | -1 | -1 | 0 | -2 | -1 |
| Marina | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -1 | 0 |
| **Phys Score** | **0** | **-2** | **-3** | **-1** | **-4** | **-5** | **-3** | **-6** | **-4** | **-4** | **-6** | **-6** |
| Habitat Potential | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | -3 | -3 | -3 | -3 |
| Shellfish | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **Bio Score** | **3** | **3** | **3** | **0** | **0** | **0** | **0** | **0** | **-3** | **-3** | **-2** | **-3** |
| Human Disturbance | 0 | 0 | 0 | -0.5 | -1 | -0.5 | 0 | -0.5 | -0.5 | -1 | -0.5 | 0 |
| Accessibility | 0 | -1 | -0.5 | -1 | 0 | 0 | -1 | -1 | 0 | 0 | 0 | -0.5 |
| **Access Score** | **0** | **-1** | **-0.5** | **-1.5** | **-1** | **-0.5** | **-1** | **-1.5** | **-0.5** | **-1** | **-0.5** | **-0.5** |
| Educatioal Opportunity | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Public Viewing | 3 | 0 | 0 | 0 | 3 | 3 | 0 | 3 | 3 | 3 | 3 | 0 |
| **Community Score** | 5 | 0 | 0 | 2 | 3 | 3 | 0 | 3 | 3 | 3 | 3 | 0 |
| **Final Score** | **23** | **15** | **14.5** | **14.5** | **13** | **12.5** | **11** | **10.5** | **10.5** | **10** | **9.5** | **5.5** |

*Table 3. Final sites chosen for concept designs with scores, deficiencies, and benefits.*

| Name | Score | Parametric Description | Goal(s) | Tactic |
|---|---|---|---|---|
| **SR-08 & SR-09**<br>**Bartram's Garden** | 23 | Moderate energy, high biological potential, good access, and high visibility/education opportunity | Habitat & Water Quality Uplift | Hybrid living shoreline consisting of shallow subtidal freshwater mussel beds and terraced emergent vegetation |
| **DR-15**<br>**Windy Point** | 14.5 | Moderate physical score due to poor condition, high biological potential, and moderate access. No outreach opportunity available. | Erosion control | Structural living shoreline consisting of a series of shallow subtidal breakwaters to promote natural vegetation expansion in the lee |
| **SR-04**<br>**Paine's Park** | 14.5 | Moderate physical score due to poor condition, high biological potential | Habitat & Water Quality Uplift | Hybrid living shoreline consisting of shallow subtidal freshwater mussel beds and terraced emergent vegetation |


*Figure 16. Locations of the final sites selected for living shoreline conceptual designs along the Delaware River (DR) and Susquehanna River (SR).*

# Data Collection and Modeling for Selected Sites

Sites were revisited that displayed high feasibility over a diverse range of goals to gather high resolution elevation data in order to develop conceptual designs that would take into account tidal prism, site-specific topography/bathymetry, and pre-existing structural conditions

## Bathymetric Data Collection and Elevation Modeling

During July 2017, Philadelphia Water Department (PWD) staff collected bathymetric point data using a HyDrone remote control catamaran platform consisting of a Leica GPS with transducer, data collector, and SonarMite Echo Sounder mounted on either the side of a boat. All survey points were collected at high tide ±2hrs in order to survey the entire inter and shallow subtidal regions of each site (Appendix A). The target range of survey was confirmed via mapping and visual inspection. The typical method for collecting data began by operating the HyDrone or boat along the littoral edge of edge of target site, then the riverside extent of the target area. This was followed by a slalom back and forth (A1) working between the defined extents of the target area. An easting, northing, water top elevation, and depth was collected every 2 feet. This data was stored on the Leica data collector where it could then be retrieved in the office for processing.

The collected data was formatted into a table with fields labeled X, Y, and Z. This table was uploaded to GIS, where the geoprocessing tool was used to create point features. These point features were created using the X and Y locations (latitude and longitude) of the data, while the Z value (elevation) is stored. To assist in the next step of interpolating the values between points, a convex hull polygon was created around the original dataset to serve as a study area boundary. Modeling of the collected points using Empirical Bayesian Kriging Approach (Geostatistical Analyst) outputted both a digital elevation model (DEM; A2) and an interpolation error map (A3). Model parameters used were the following: Semi-variogram: K-Bessel, Subset Size: 100, Overlap: 5, Simulations: 100, and Neighbors: 15 (10 min).

As expected, lowest potential model error fell within high point density areas, whereas high potential errors fell beyond the surveyed area or between sinusoidal wavelengths (Figure 18). Average vertical error was at or below +/- 0.3ft. Future HyDrone surveys will employ a grid-based pattern to reduce error and improve modeling predictability. A gridded dataset would also lend itself toward elevation interpolation via triangular irregular networks (TINs).

## Freshwater Mussel and Vegetation Habitat Suitability

Digital Elevation Models were used to determine potential areas for restoration of mussel and submerged aquatic vegetation (SAV) beds and low and high marsh vegetation communities (Appendix B). The local datums referenced for determining zoning of project areas, and abbreviations, are described in Figure 17. High marsh vegetation areas were positioned between mean higher high water (MHHW) to mean tide level (MTL), and low marsh vegetation between MTL and mean low water (MLW). Mussels zones were further divided into shallow (2' below mean lower low water (MLLW)), intermediate (4' below MLLW), and deep (7' below MLLW, Figure 17). Conceptual design calculations converted Imperial Units (feet) to the International System of Units (meters), as per Partnership for the Delaware Estuary protocol, to calculate the relative distribution of habitat areas across each site, presented in Table 4.**Error! Reference source not found.**

| Habitat Zones | (SR08-09) Bartram's Garden | (DR15) Windy Point | (SR04) Paine's Park |
|---|---|---|---|
| High Marsh | 205 | 275 | 70 |
| Low Marsh | 440 | 7,195 | 1,085 |
| Mussels & SAVs | 4,355 | 0 | 1,315 |
| Total Area | 25,170 | 17,846 | 4,620 |

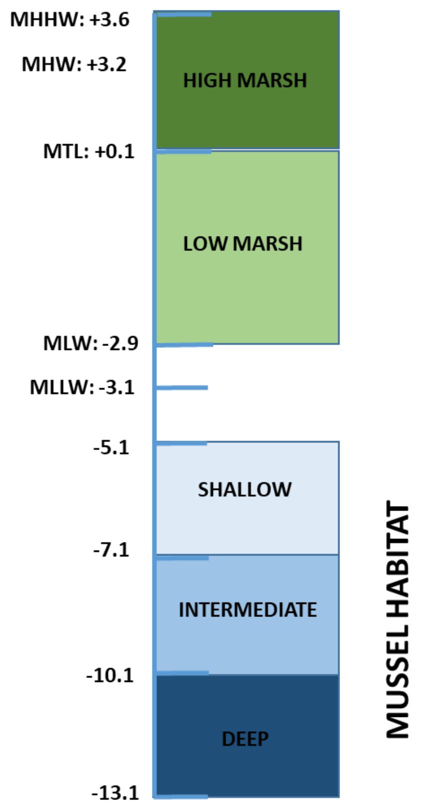


*Figure 17. Tidal datums in Philadelphia, PA and habitat zones. All datums are in feet relative to NAVD88.*

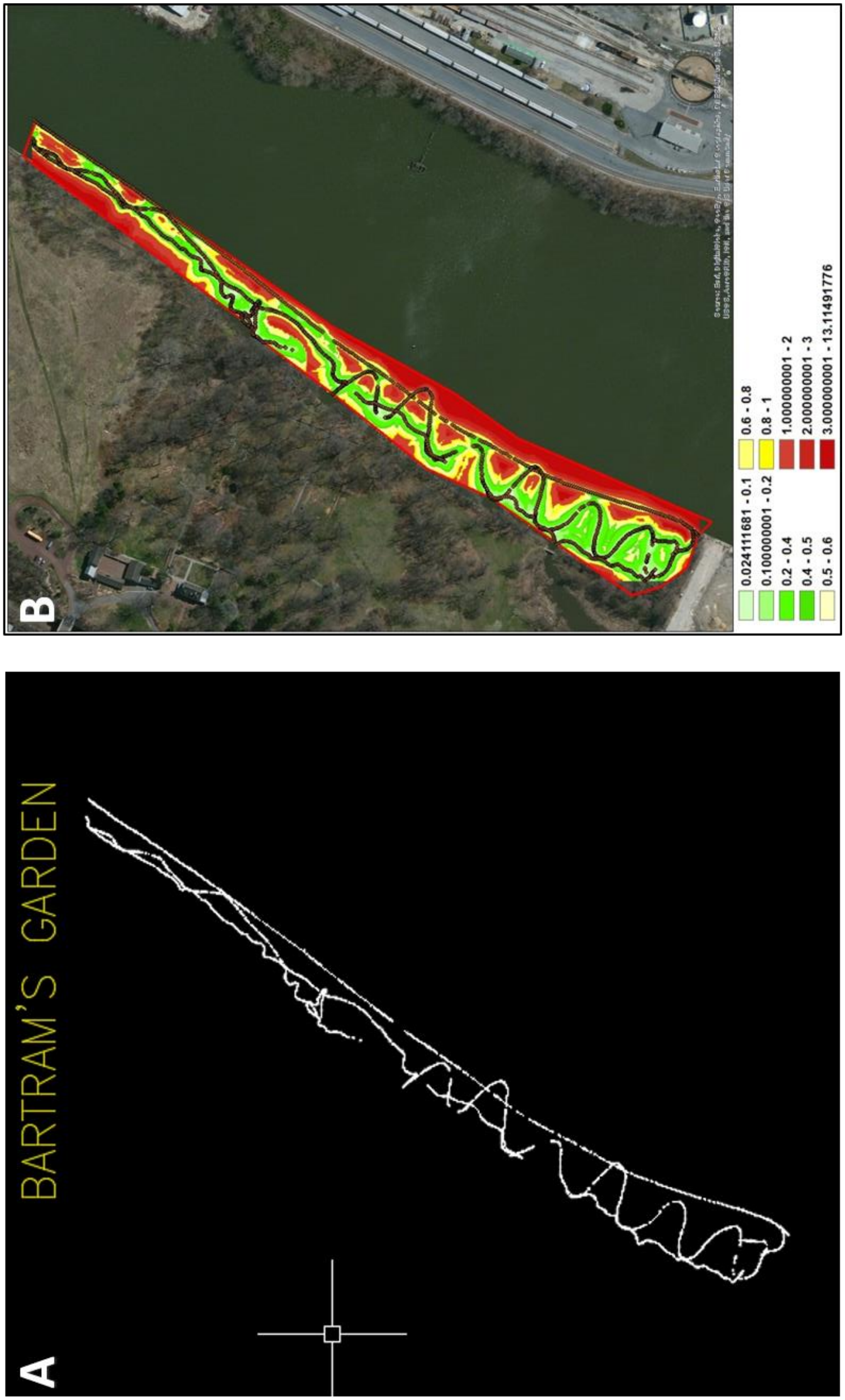


*Figure 18. A) Example of HyDrone™ collected elevation data; B) Example of error from interpolated DEM data using the Empirical Bayesian Kriging method*

# 5.0 Results and Discussion

## Conceptual Living Shoreline Designs

Conceptual designs for the selected sites were created to meet site-specific goals of erosion control, habitat enhancement, water quality, or a combination. Sites with a goal of erosion control received designs intended to stabilize the shoreline, thus reducing the lateral landward migration of the land-water interface, and/or creating conditions for the facilitation of sediment accrual. Sites with a goal of habitat enhancement received designs intended to enhance biodiversity and improve the habitat provision services of coastal lands and waters (e.g., food, shelter and nursery habitat) through ecological uplift. This included designs to restore or recreate habitat such as shellfish beds, beaches, or marshes and/or projects that provided improvements to existing habitat for fish and wildlife. Sites with a goal to maintain or improve water quality received designs intended to either facilitate reductions in, or reduce the concentrations of, nutrients, contaminants, and/or suspended solids that could inhibit ecosystem functions. All conceptual designs are compiled in Appendix C.

### Bartram's Garden (Appendix C1)

The Bartram's Garden design had the primary goals of habitat and water quality uplift. To meet those goals, the living shoreline design included two sub-areas (treatment 1 & 2) to which hybrid treatments consisting of shallow subtidal mussel beds and a mosaic of terraced intertidal vegetation zones would be applied. Mussel beds will provide energy attenuation through the structural configuration of the pens along the waterward margin, as well as water quality uplift through filtration of nutrient rich-particulate matter by the mussels. The enhanced water clarity would be expected to facilitate the establishment of local submerged aquatic vegetation (SAV) and the transport of the filtered nutrients to the benthos would provide an energy-rich substrate for growth and expansion. Mussel pens (Figure 19) would be composed of low-relief materials (e.g. shell, reclaimed wood, etc…) with gaps along the landward and waterward margins will allow for the delivery of particulate food matter and removal of waste, while the continuous length of materials on the side of primary river flow will help minimize shear-stress and maximize benthic stability for mussel persistence. The gaps allow for faunal passage at all tide stages. The mussel pens can be stocked with common freshwater mussel species and local SAV varieties. A wide low marsh habitat zone can be established using soft, bio-based materials (coir fiber and shell) to facilitate natural sedimentation across a terraced profile parallel to the current vegetative edge. High marsh areas, located near MHHW can be mosaicked throughout the low marsh area, taking advantage of natural sedimentation areas for placement. The mosaicked approach will result in higher vegetation biodiversity that will be able to respond to short-term changes in water levels (e.g. flooding from storms and drought) and elevation (e.g. periodic scour and sedimentation patterns) by having a diverse community to take advantage of available niches as the low/high marsh boundary fluctuates.

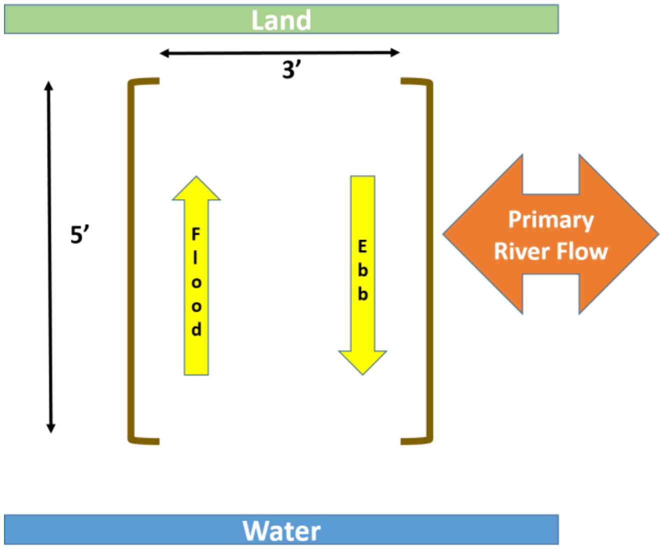


*Figure 19. Schematic of proposed mussel pen design. Brown brackets represent the low relief structural materials to disrupt the primary river flow benthic shear stress. Black arrows describe the relative dimensions of the structure. Gaps on the water and landward margins allow for ebb and flood tidal exchange as well as for faunal passage.*

## Windy Point (Appendix C2)

The proposed living shoreline design at Windy Point (DR-15) involves wave breaks to attenuate the large vessel wake energy from the Delaware River and edge stabilization along an intertidal drainage creek to meet the goal of erosion control. Offshore structures in four or more feet of water would decrease incoming energy from boat wakes and further encourage natural sedimentation to occur. The segment pattern on off-set parallel rows of structures will help to attenuate energy across the entire length of the site, while allowing access for sediment to internal elevation building and faunal passage. Survey data showed that depth profiles along the site precluded freshwater mussel habitat augmentation, but future efforts in the lee of the wave attenuation structures may be possible. To evaluate freshwater mussel potential in proximity to the structures, monitoring data regarding sedimentation and benthic stability should be gathered post installation. Multiple cusps of coir logs installed from the MTL to MLW across the landward portion of the site would encourage sedimentation and thus a gain in elevation resulting in more suitable habitat for low-marsh vegetation (habitat uplift). Marsh edge stabilization would decrease undercutting and thus protect the vulnerable leading edge of the marsh. A tidal creek's outflow occurs to the southwest and travels east creating a natural channel. This channel could be stabilized using oyster castles or other natural hard structures to prevent future scouring of established low marsh vegetation. Although current elevation profiles are not amenable to large scale high marsh development, the partitioning of the low marsh area in to multiple sub-cells, will allow for localized sediment accrual. Areas of high sediment trapping may be available two-three years post implantation for augmentation to high marsh areas.

## Paine's Park (Appendix C3)

The primary goals at Paine's Park (SR-04) were habitat and water quality uplift. To meet those goals, a design consisting of an increase in low marsh habitat and establishment of mussel and SAV habitat is proposed. As at Bartram's Garden, multiple sub-treatment areas would be installed along the site to compartmentalize the design and increase its stability. By installing three treatments having subtle differences in design, scientific tools could be used to adjust for minor variations in tidal flow and overland runoff. A limited number of freshwater mussels were already found in this location; therefore, the living shoreline design would attempt to increase mussel carrying capacity to promote a more robust population comprised of more species and individuals. Planting and seeding of submerged aquatic vegetation would further encourage mussel propagation as they are often found in tandem. The mussel habitat zone is of uniform width along the study area, which is important in comparing results across the three treatment locations. Mussel pens (Figure 19) could be installed across the site, since the depth profile is consistent across the site. Stabilization materials such as coir logs or timber would help stabilize an edge and help natural sedimentation to occur that would promote establishment of low marsh vegetation.

# 6.0 Conclusion

As sea level rise presents numerous challenges for people along the Pennsylvania coastline, tidal wetlands remain the most valuable buffer for rising seas levels and vital habitat for fish and wildlife. Unfortunately, southeast Pennsylvania has lost >95% of its coastal marshes, the greatest percent loss in the system. Ecologically sound measures are needed to protect these marshes from erosion (horizontal loss) or drowning (vertical loss), and accentuation of marsh acreage or condition would promote greater coastal resilience. The first step in a strategic and scientific approach to living shoreline planning and installation is the identification of suitable project sites. Site-specific impairments can exist that are not visible using desktop methods, and so both desktop and on-the-ground site assessments are needed for the initial selection of suitable locations for living shoreline projects, as well as to identify which living shoreline tactics might match local site conditions and vulnerability. The goal of this study was to identify locations that were amenable to living shoreline implementation within the coastal zone of southeast Pennsylvania and to prepare initial conceptual designs for a subset of candidate living shoreline sites that appear most suitable based on feasibility of implementation and existing physical and biological conditions. A methodology was developed to:

1. Identify potential sites at the landscape level,
2. Apply a field-based rapid assessment methodology at the previously identified sites to characterize current conditions, identify factors driving impairment, and set site-specific goals,
3. Prepare initial conceptual ideas for living shoreline designs that match appropriate tactics to site conditions.

Site selection was based on whether a location was deemed to: 1) be most suitable for a living shoreline, 2) benefit from increased ecosystem services provided by the living shoreline, and 3) serve as demonstration sites to show the importance of protecting and enhancing shorelines. The conceptual designs developed for a subset of sites were prepared to inform interested parties of the particular living shoreline applications that would address the site-specific goals and provide valuable ecosystem service uplift.

The rapid site assessment was successful in identifying site-specific goals and drivers, allowing for the selection of the appropriate project type at each site. By understanding the primary drivers that reduce resilience at a site, interested parties are able to either choose sites that play to the strengths/interests/goals of their restoration group, or assemble the appropriate team for project development at a specific site. For example, ecologists may prefer to develop a project at a location where condition and biological potential are low under a low energetic forcing, whereas engineers may choose to work at site requiring a high level of energetic attenuation, but that has high biological potential. Alternatively, if a site with high energetics and low biological potential is in dire need of intervention, a diverse team of engineers and ecologists can be assembled to address both concerns during the design phase. Finally, if site selection is dependent of outreach and education opportunities, the rapid field assessment can partition the potential sites by this factor level, from which further considerations can progress.

In this study conceptual designs were developed for Bartram's Garden, Windy Point, and Paine's Park. Attainable goals for Bartram's Garden and Paine's Park were deemed to be habitat and water quality uplift (as well as outreach). The design for both sites focused on shallow subtidal mussel pens to attenuate energy waterward of the existing shoreline, and to provide water quality uplift through the filtration of the resident bivalve population. Additionally, as SAV cover has been positively correlated with freshwater mussel presence, these designs will be suitable for SAV planting, providing additional habitat for juvenile fish, benthic invertebrates, and infaunal communities. Along the existing shorelines at each site, a habitat mosaic of low and high marsh communities was proposed. By integrating a diverse vegetation community, successful retention is maximized for short-term fluctuations in conditions (e.g. flooding, ice scour, excessive/minimal sedimentation events) that may affect boundary transition. At Windy Point, the primary goal was erosion control. Due to the poor condition of the site and the proximal armoring and likely resultant high energy regime, a series of off-set segmented breakwaters were proposed. Gaps between breakwaters would allow for sediment and faunal passage, while the off-set placement of parallel rows would provide energy attenuation across the site. There would also be future potential for freshwater mussel habitat in the lee of breakwaters, dependent on sedimentation and substrate stability. Low and high marsh communities in compartmentalized locations along the existing shoreline would increase habitat values and buffer against erosion. It is important to note that before the designs could be implemented, further data collect is necessary to confirm modeled elevation profiles and test geotechnical support of the substrate.

# 7.0 Future Research

Future research includes retesting and performing validation on the living shoreline feasibility model to assess repeatability across user skill levels. Additionally, the top site selected for living shoreline implementation, Bartram's Garden, has been funded through a PA Coastal Zone Management grant (awarded November 2018) to elevate the conceptual design to an implementation-ready design through additional high-resolution, bathymetric and geotechnical data for specific material placement locations and configurations. The designs will be subsequently shared with local regulatory agents for review and comment in order to prepare the appropriate permit applications.

Further, PDE submitted proposals for a National Fish and Wildlife Foundation Delaware Watershed Conservation Fund grant (*Living Shoreline Implementation and Planning Efforts for the Tidal, Freshwater Spectrum of the Delaware Estuary*, submitted October, 2018) and a 2019 PA Coastal Zone Management grant (*Inclusion of Freshwater Mussel Pens in Pilot Living Shorelines* submitted October, 2018) to permit and implement the previously described designs for the Bartram's Garden site identified in this study. In addition to the implementation efforts, the NFWF grant also includes tasks to employ the living shoreline feasibility model developed under this funding to coastal, freshwater Delaware and New Jersey coastlines, partnering with Delaware Department of Natural Resources and Environmental Control and NJ Department of Environmental Protection respectively, for living shoreline site and prioritization efforts.

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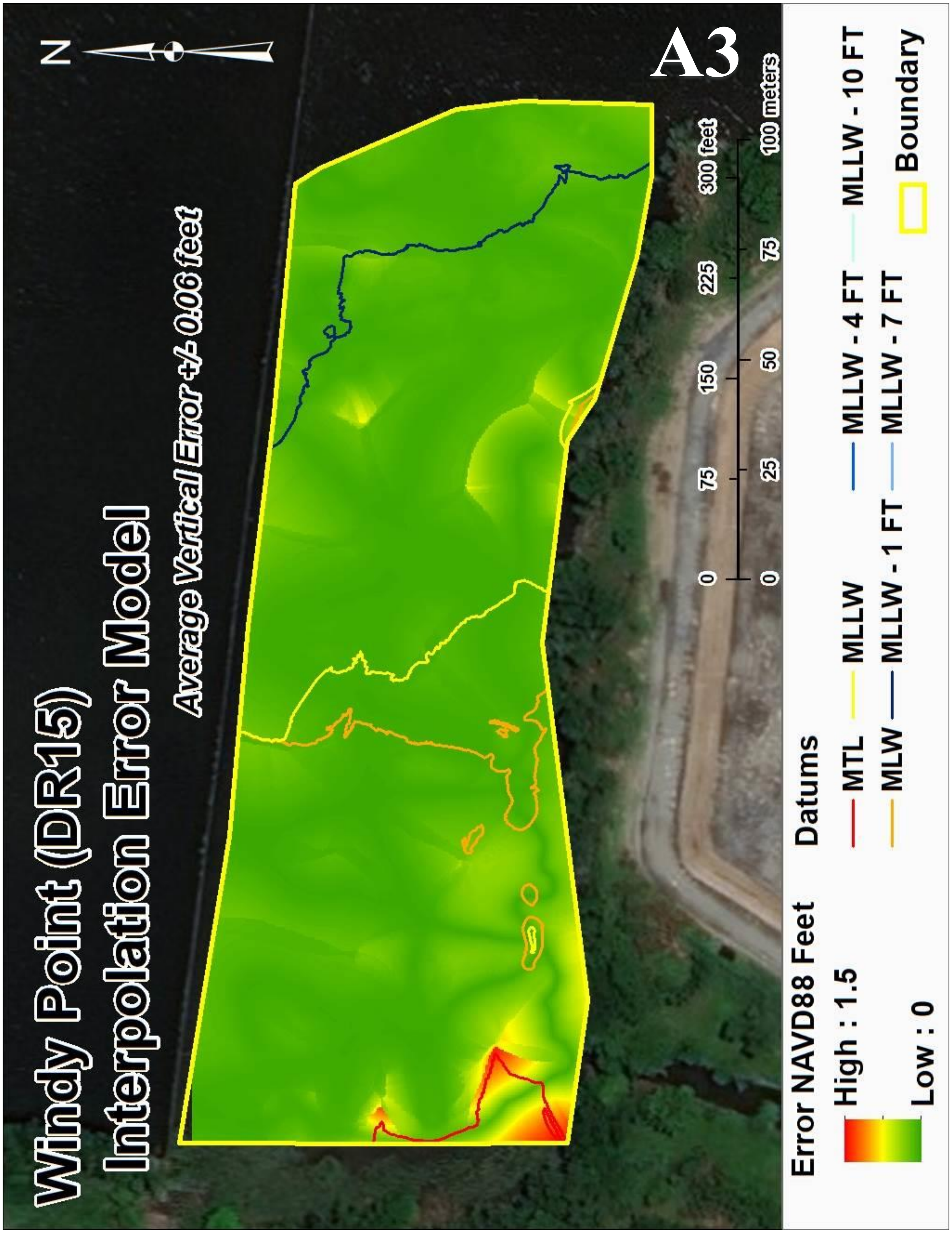
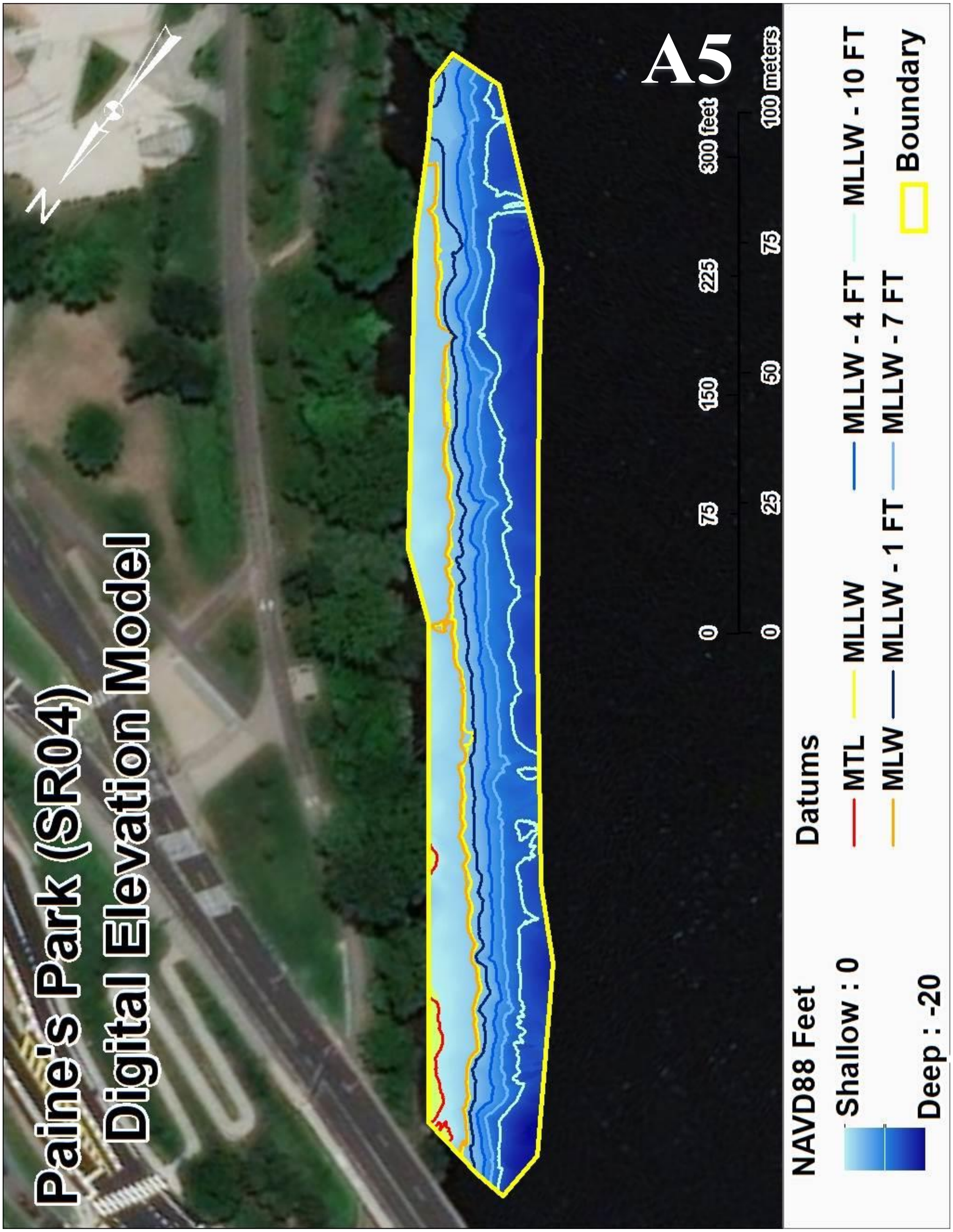
# 9.0 Appendix A: Elevation Modeling

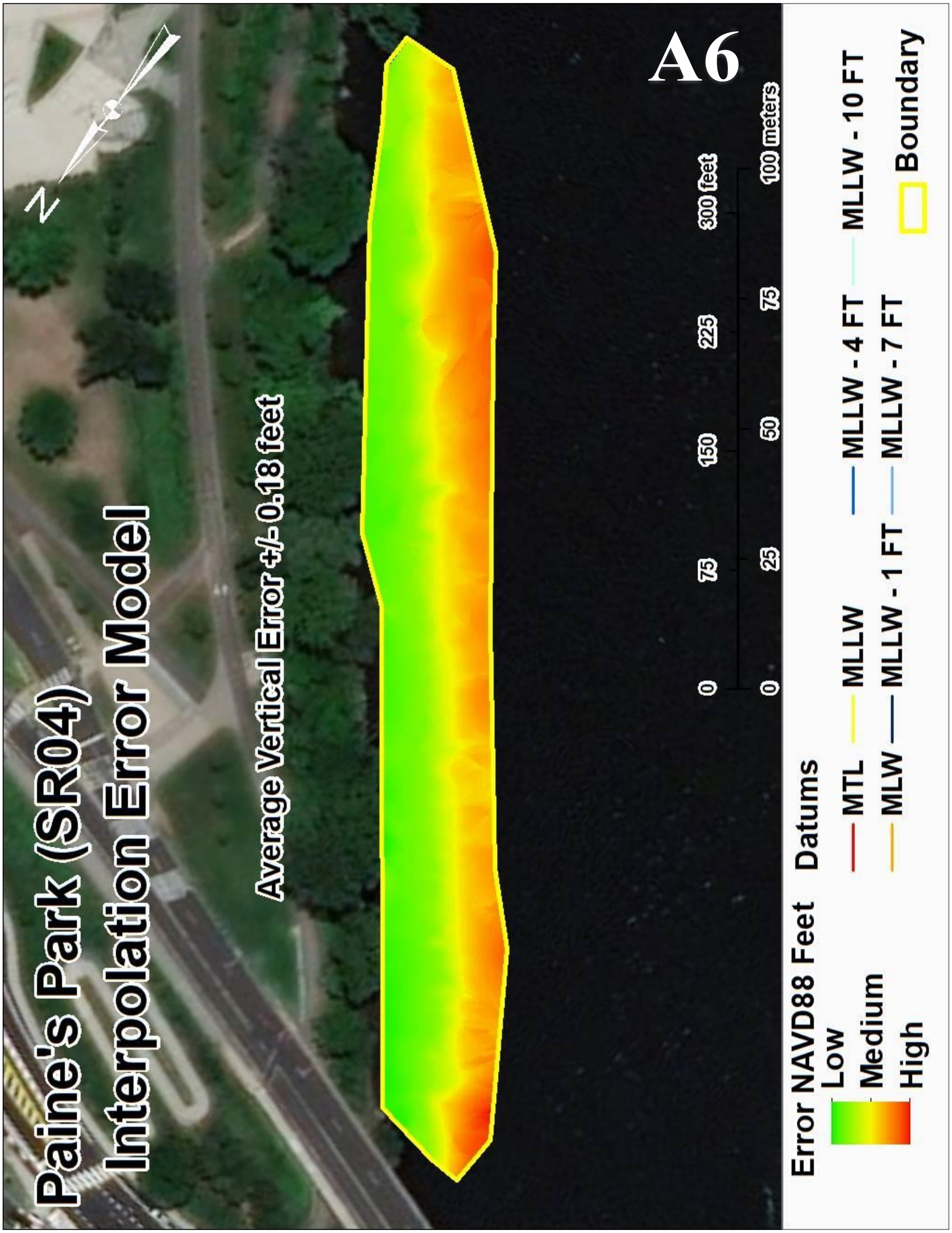

Windy Point (DR15)
A1
N
600 feet
450
300
150
0
200 meters
150
100
50
0
Legend
Area of Interest
Hydrone Data Points
S Delaware Ave

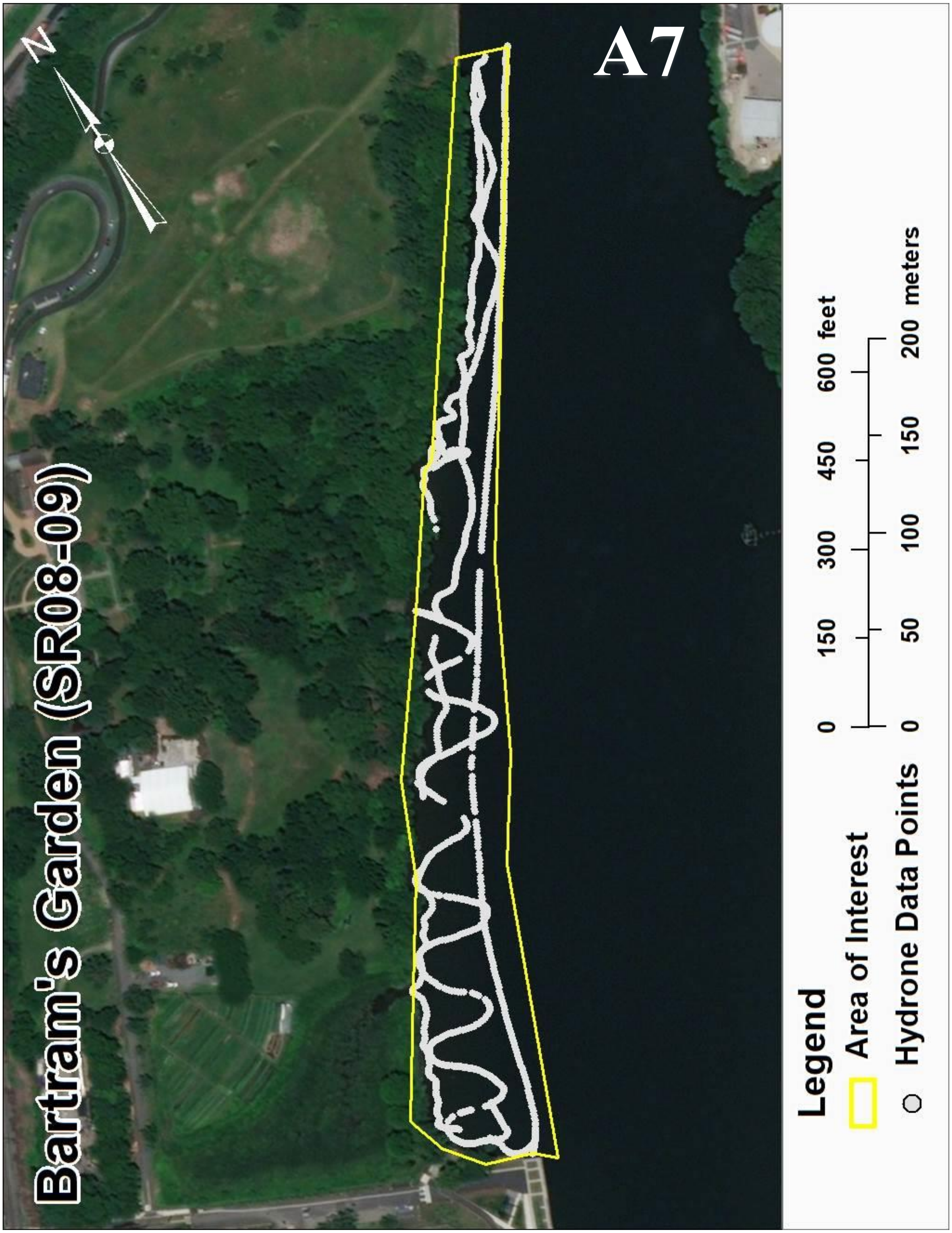
Windy Point (DR15)
Digital Elevation Model
A2
N
0
75
150
225
300 feet
0
25
50
75
100 meters
NAVD88 Feet
High : 0
Low : -5
Datums
MTL
MLLW
MLLW - 4 FT
MLLW - 10 FT
MLW
MLLW - 1 FT
MLLW - 7 FT
Boundary


Windy Point (DR15)
Interpolation Error Model
Average Vertical Error +/- 0.06 feet
A3
N
0 75 150 225 300 feet
0 25 50 75 100 meters
Error NAVD88 Feet
High : 1.5
Low : 0
Datums
MTL
MLW
MLLW
MLLW - 1 FT
MLLW - 4 FT
MLLW - 7 FT
MLLW - 10 FT
Boundary

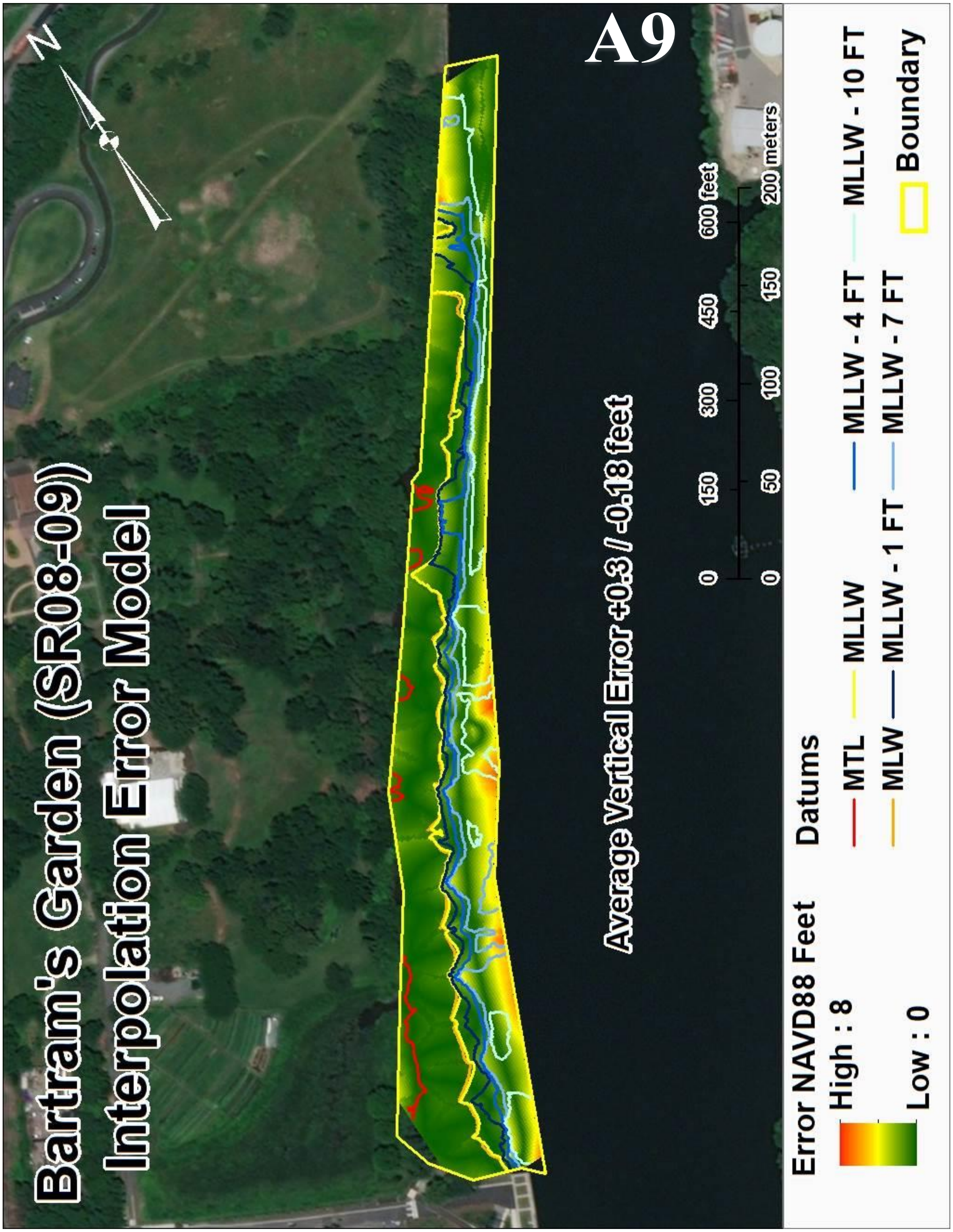

Paine's Park (SR04)
A4
N
Legend
Area of Interest
Hydrone Data Points
0 75 150 225 300 feet
0 25 50 75 100 meters


Paine's Park (SR04)
Digital Elevation Model
A5
N
0 75 150 225 300 feet
0 25 50 75 100 meters
NAVD88 Feet
Shallow : 0
Deep : -20
Datums
MTL
MLW
MLLW
MLLW - 1 FT
MLLW - 4 FT
MLLW - 7 FT
MLLW - 10 FT
Boundary

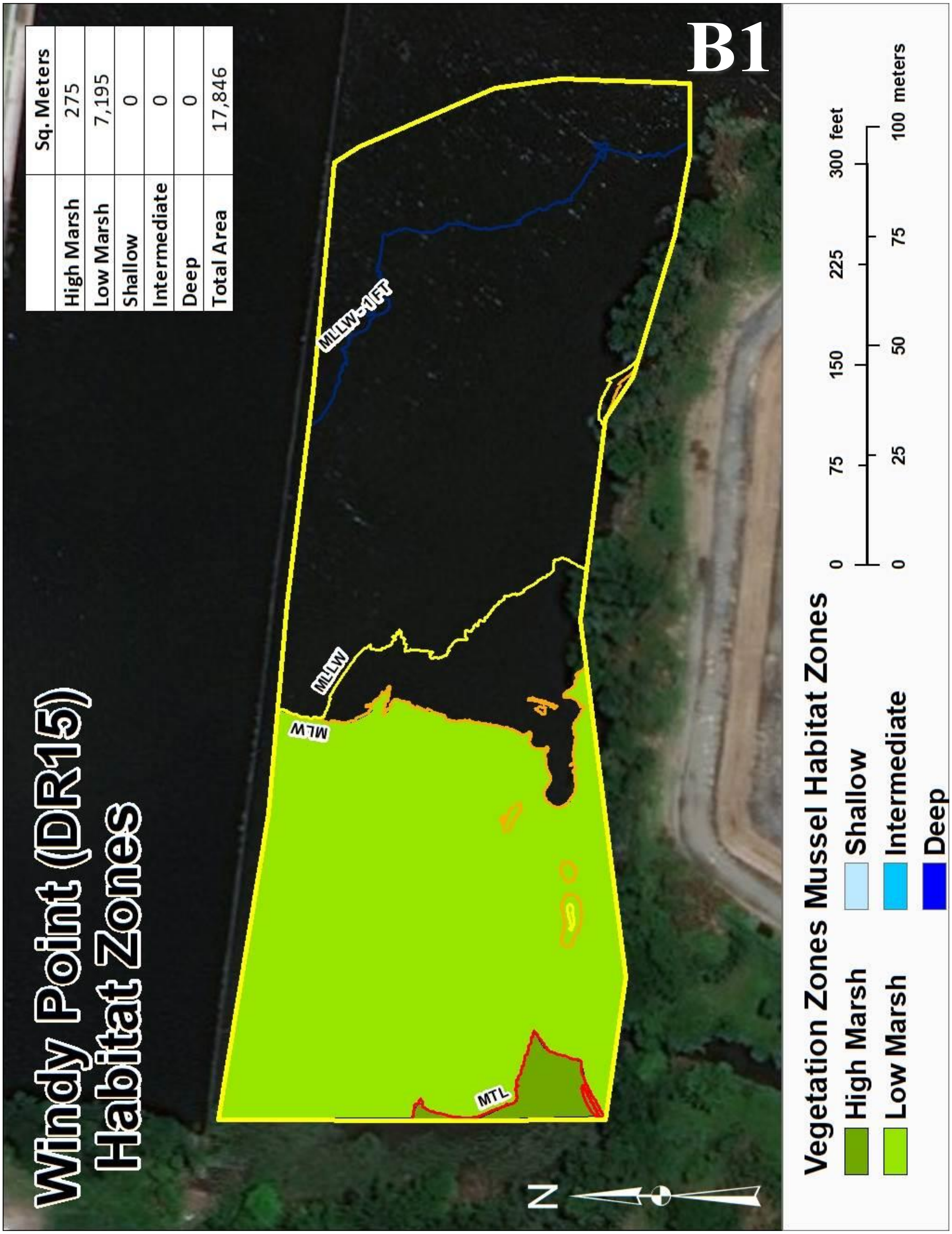

Paine's Park (SR04)
Interpolation Error Model
Average Vertical Error +/- 0.18 feet
A6
N
0 75 150 225 300 feet
0 25 50 75 100 meters
Error NAVD88 Feet
Low
Medium
High
Datums
MTL
MLW
MLLW
MLLW - 1 FT
MLLW - 4 FT
MLLW - 7 FT
MLLW - 10 FT
Boundary


A7
Bartram's Garden (SR08-09)
N
0 150 300 450 600 feet
0 50 100 150 200 meters
Legend
Area of Interest
Hydrone Data Points

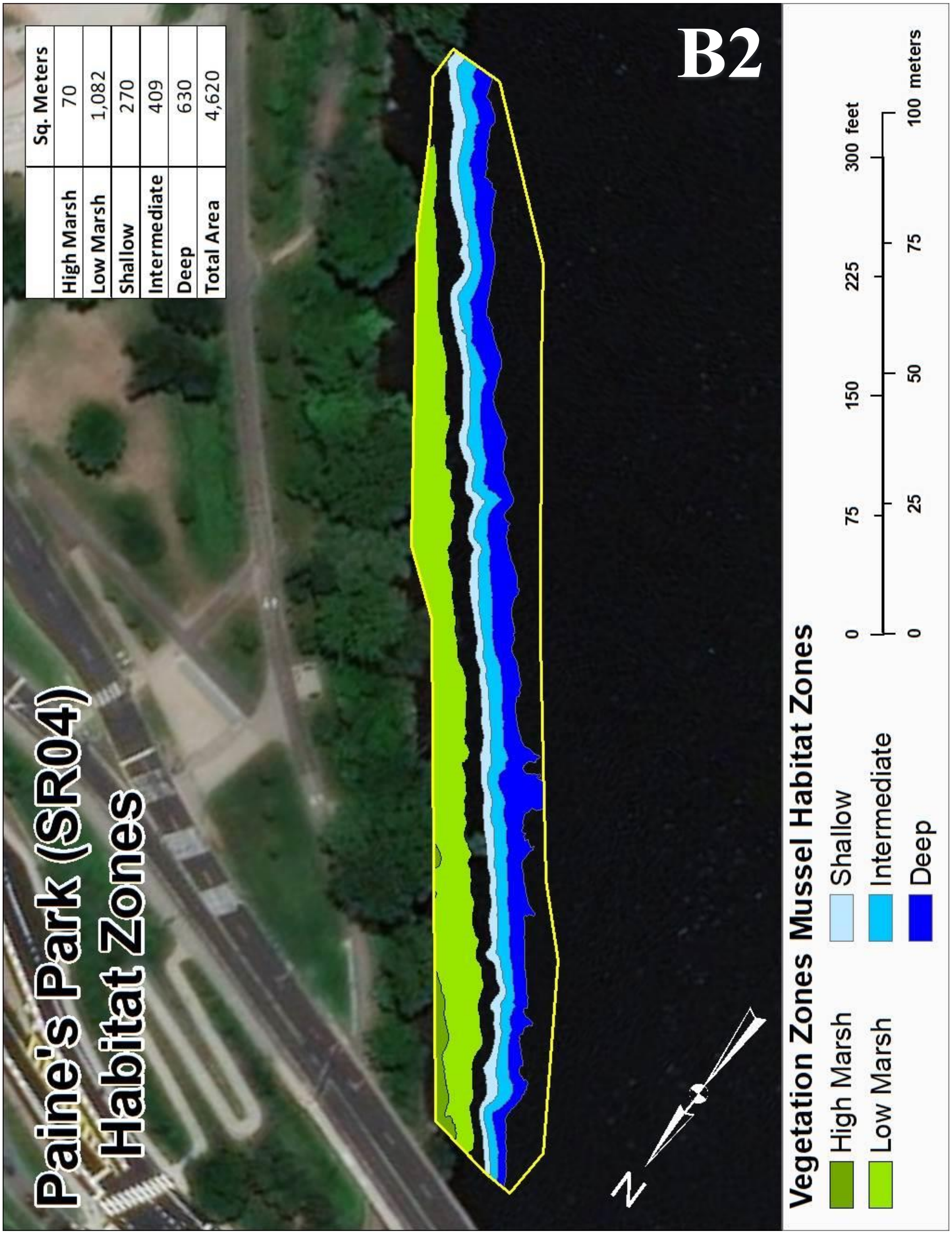
A8
Bartram's Garden (SR08-09)
Digital Elevation Model
0 150 300 450 600 feet
0 50 100 150 200 meters
NAVD88 Feet
High : 0
Low : -20
Datums
MTL
MLW
MLLW
MLLW - 1 FT
MLLW - 4 FT
MLLW - 7 FT
MLLW - 10 FT
Boundary


A9
N
Bartram's Garden (SR08-09)
Interpolation Error Model
Average Vertical Error +0.3 / -0.18 feet
0 150 300 450 600 feet
0 50 100 150 200 meters
Error NAVD88 Feet
High : 8
Low : 0
Datums
MTL
MLW
MLLW
MLLW - 1 FT
MLLW - 4 FT
MLLW - 7 FT
MLLW - 10 FT
Boundary

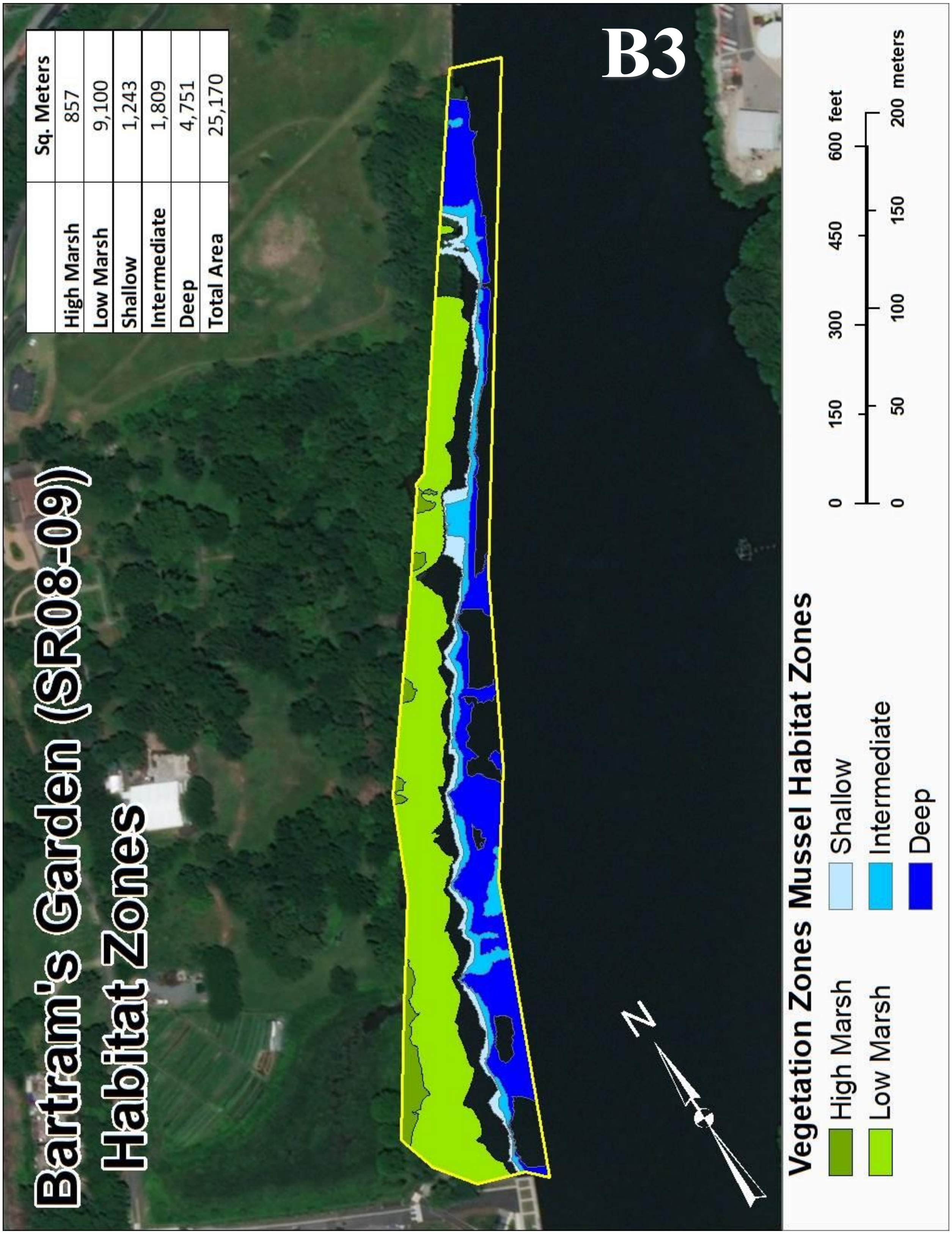
# 10.0 Appendix B: Habitat Suitability



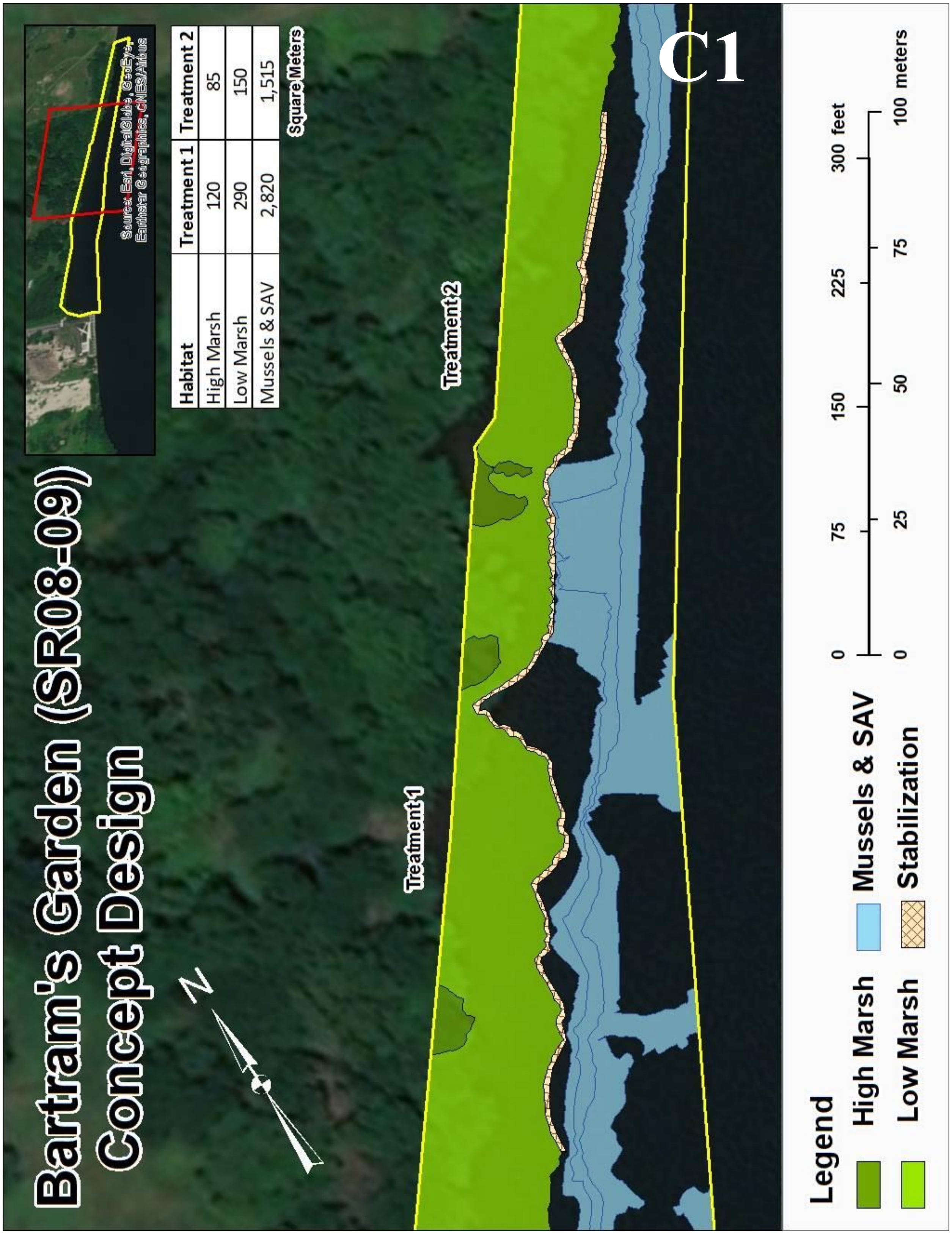
Windy Point (DR15)
Habitat Zones
B1
Sq. Meters
High Marsh 275
Low Marsh 7,195
Shallow 0
Intermediate 0
Deep 0
Total Area 17,846
MLLW -1 FT
MLLW
MLW
MTL
N
Vegetation Zones
High Marsh
Low Marsh
Mussel Habitat Zones
Shallow
Intermediate
Deep
0 75 150 225 300 feet
0 25 50 75 100 meters



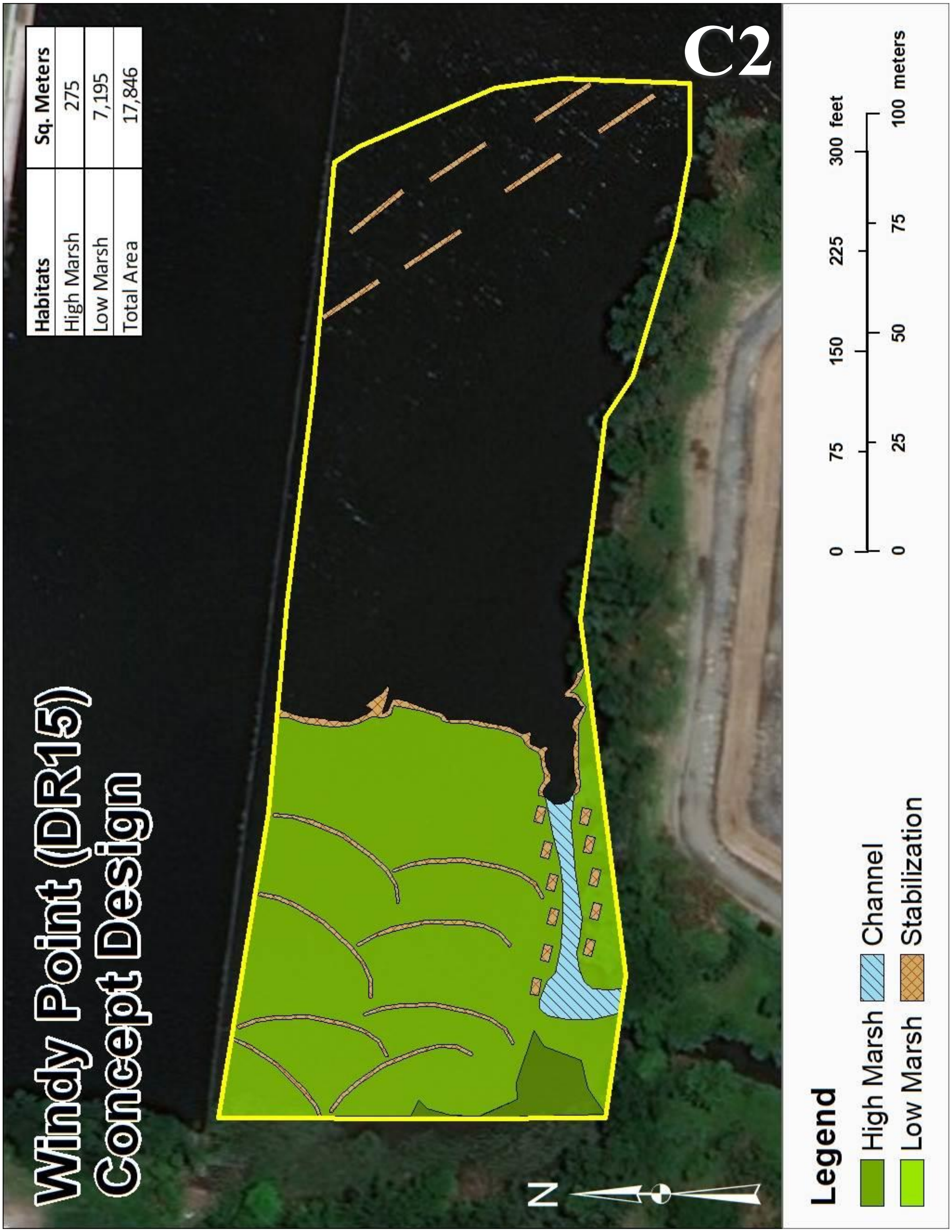
Paine's Park (SR04) Habitat Zones
B2
Sq. Meters
High Marsh 70
Low Marsh 1,082
Shallow 270
Intermediate 409
Deep 630
Total Area 4,620
Vegetation Zones
High Marsh
Low Marsh
Mussel Habitat Zones
Shallow
Intermediate
Deep
N
0 75 150 225 300 feet
0 25 50 75 100 meters

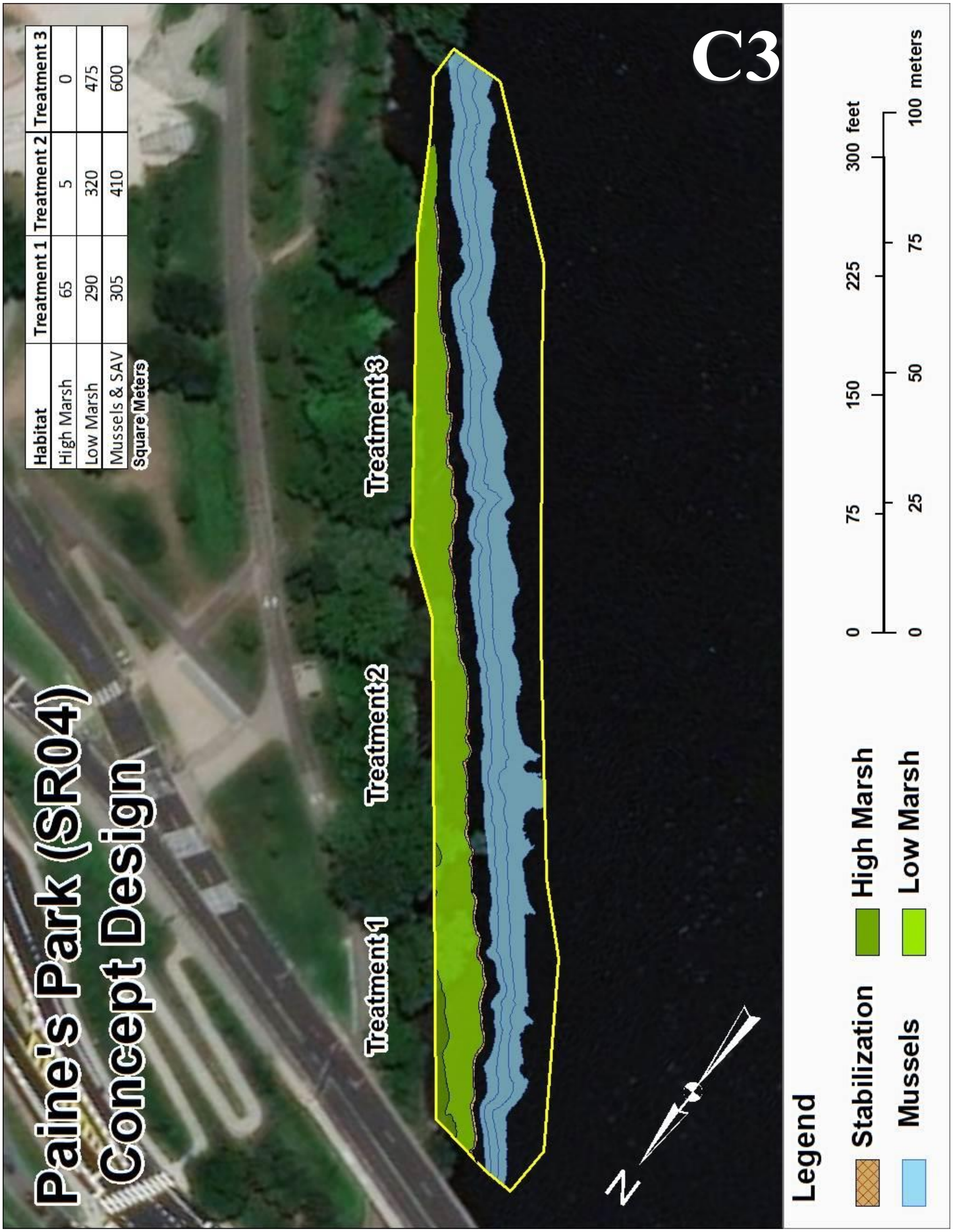

Bartram's Garden (SR08-09)
Habitat Zones
B3
High Marsh 857
Low Marsh 9,100
Shallow 1,243
Intermediate 1,809
Deep 4,751
Total Area 25,170
Sq. Meters
Vegetation Zones
High Marsh
Low Marsh
Mussel Habitat Zones
Shallow
Intermediate
Deep
N
0 150 300 450 600 feet
0 50 100 150 200 meters

# 13.0 Appendix C: Conceptual Designs




| Habitat | Treatment 1 | Treatment 2 |
|---|---|---|
| High Marsh | 120 | 85 |
| Low Marsh | 290 | 150 |
| Mussels & SAV | 2,820 | 1,515 |


Windy Point (DR15)
Concept Design
C2
Habitats | Sq. Meters
High Marsh | 275
Low Marsh | 7,195
Total Area | 17,846
N
0 75 150 225 300 feet
0 25 50 75 100 meters
Legend
High Marsh
Low Marsh
Channel
Stabilization


Paine's Park (SR04)
Concept Design
C3
Habitat | Treatment 1 | Treatment 2 | Treatment 3
High Marsh | 65 | 5 | 0
Low Marsh | 290 | 320 | 475
Mussels & SAV | 305 | 410 | 600
Square Meters
Treatment 1
Treatment 2
Treatment 3
N
Legend
Stabilization
High Marsh
Mussels
Low Marsh
0 75 150 225 300 feet
0 25 50 75 100 meters