GEOTECHNICAL APPENDIX B
FOLLY BEACH, SOUTH CAROLINA

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Geotechnical and Dam Safety Section

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1.0 INTRODUCTION

Folly Beach, South Carolina, is located 12.0 miles south of Charleston, South Carolina, and measures 6.1-miles in length. The island is situated between Morris Island and Lighthouse Creek to the northeast and Kiawah Island and Stono Inlet to the southwest. The location of Folly Beach, downdrift of Charleston Harbor jetties, has led to sediment deprivation increasing the need for shoreline protection and restoration. The original 1993 re-nourishment project on Folly Beach covers approximately 28,200 linear ft (5.35 linear miles) of shoreline (Figure 1). The project limits extend from the Folly Beach County Park (southeast end of Folly Beach) to the Lighthouse Inlet Heritage Preserve (northeast end of Folly Beach). Since project authorization in 1993, several re-nourishment projects have placed large quantities of sand on Folly Beach. This has resulted in the depletion of sand resources offshore and now a re-evaluation of existing offshore geotechnical and geophysical data is needed to identify other sand resources offshore of Folly Beach. Geotechnical and geophysical offshore investigations have occurred from 1991 to 2019 to identify dredge-able, beach-compatible sands. This report presents the collective geotechnical and geophysical analyses offshore of Folly Beach and identifies the quality and quantity of potential offshore sand resources to sustain Folly Beach for the next 50 years.

1.2 RENOURISHMENT HISTORY

Before project authorization and allocation of funds in 1993, several nourishments along the southern end of Folly Beach took place during the 1980s. Each nourishment came from the Folly River and placed less than 500,000 yd^3. These nourishments not only provided shore protection to Folly Beach but also helped maintain the Folly River to be at a navigable depth. Following these nourishments in the1980s, a shoreline protection plan was developed in the early 1990s. Initial construction of the "Folly Beach Shoreline Protection Project" was completed in May 1993. The initial construction placed approximately 2,800,000 yd^3 of sand from the Folly River (GDM, 1991). Following initial construction, the first periodic nourishment was completed in 2005, placing 2,338,000 yd^3 of sand from borrow area A (PIR, 2013). In June 2007, under the Public Law (PL) 84-99 assistance program (Rehabilitation for Non-Federal Flood Control Projects) 486,000 yd^3 of sand was placed on Folly Beach from borrow area B. In 2013, the Charleston County Parks and Recreation Commission (CCPRC) sponsored a full nourishment within the Folly Beach County Park (southern spit of Folly Beach) by placing 415,000 yd^3 of sand. In the same year, the CCPRC also supported the construction of a terminal groin to prevent sediment from bypassing the southern spit of Folly Beach. Shortly thereafter in 2014, a second periodic nourishment was completed placing 1,419,385 yd^3 of sand from borrow areas A, B, C, and D resulting in depletion of these four borrow areas (PIR,2013; Figure 2).The last nourishment occurred in 2018 and again utilized the Folly River placing 750,000 yd^3 of sand on Folly Beach. Table 1 summarizes the total volume of sand placed on Folly Beach from 1993 to 2018.

Table 1. Renourishment history along Folly Beach since project authorization in 1993.

Year	Primary Funder	Borrow Location	Volume (yd^3)
1993	Federal	Folly River	2,800,000
2005	Federal	A	2,338,000
2007	Federal	B	486,000
2013	Local	Folly River	415,000
2014	Federal	A, B, C, and D	1,419,385
2018	Local	Folly River	750,000
			7,959,385

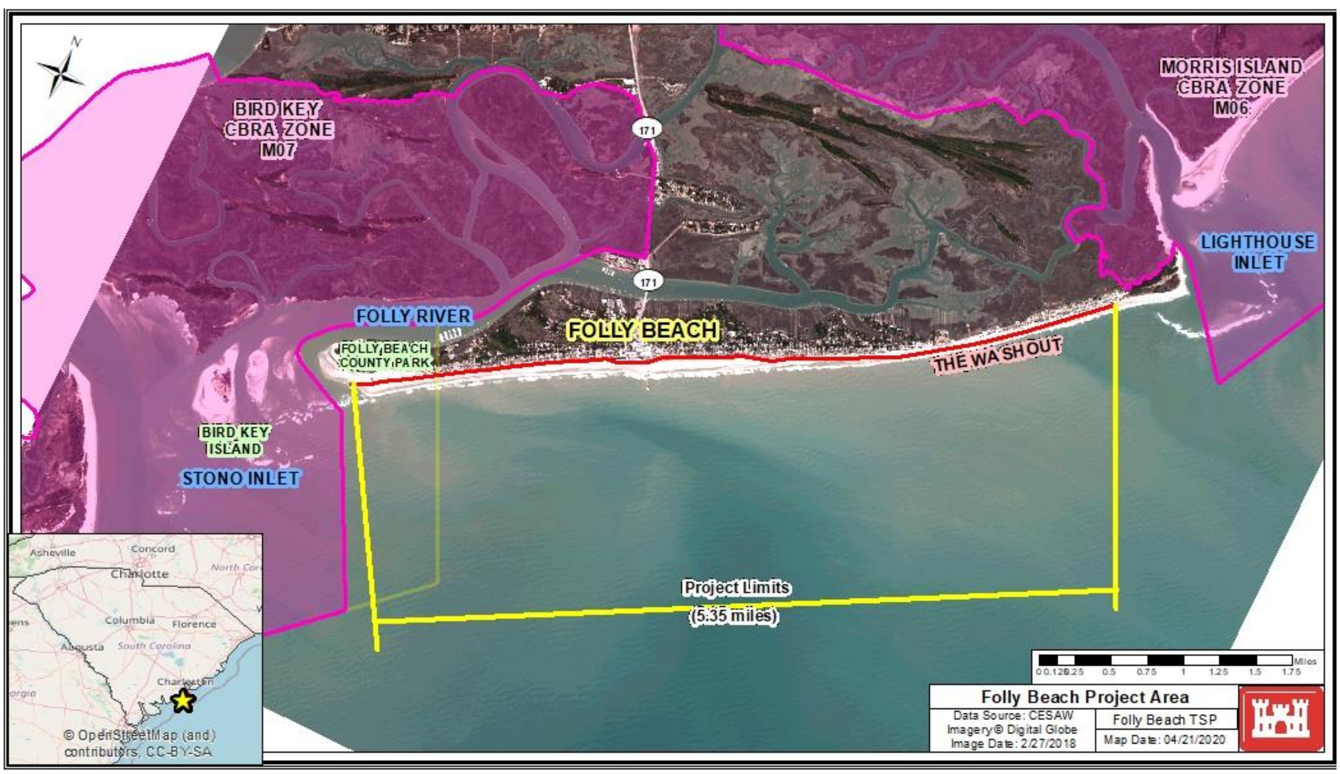

Figure 1. Folly Beach, South Carolina, study area showing project placement limits along the island from the original 1993 study. Adjacent to the project limits highlighted in red are Coastal Barrier Resource Act Zones (CBRA).

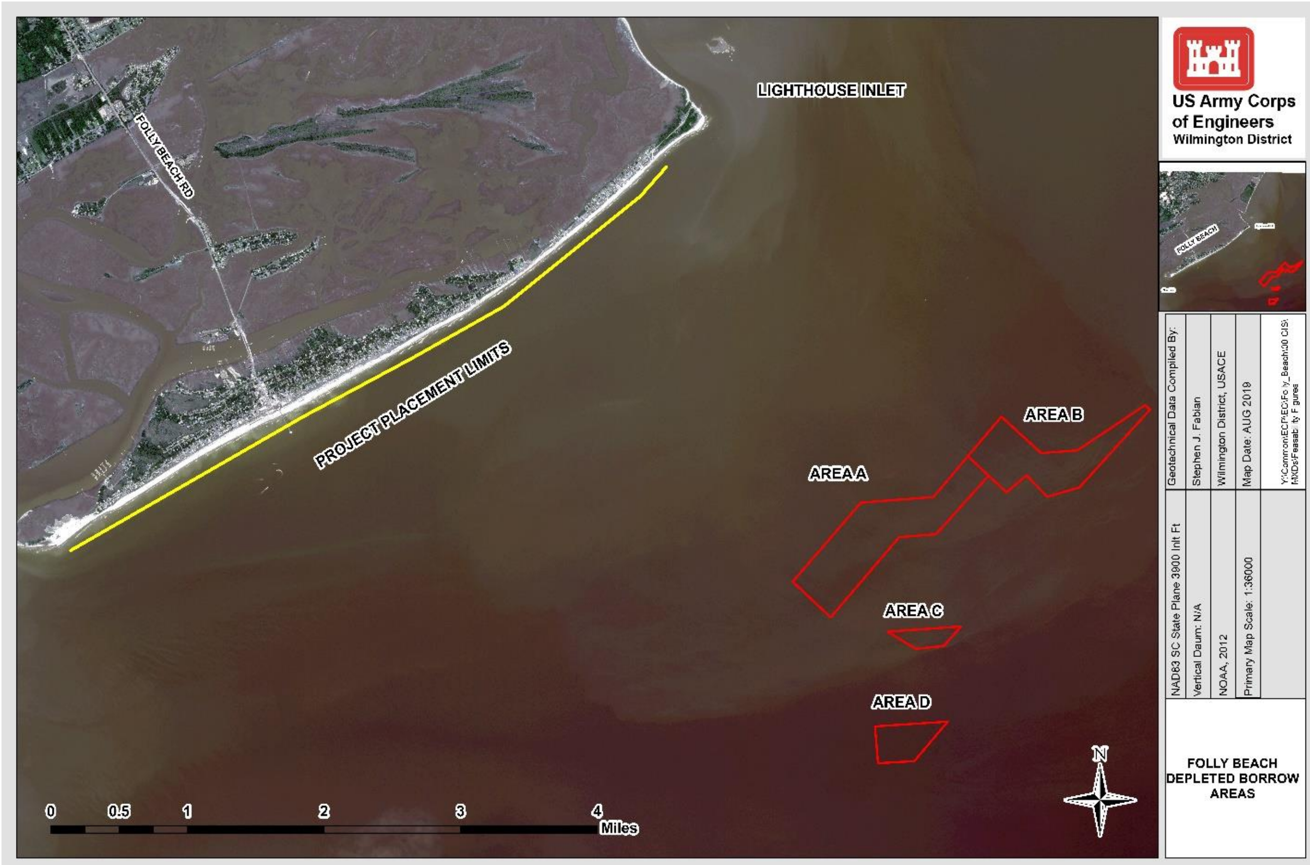

Figure 2. Depleted in 2014, offshore borrow areas A, B, C, and D were used for three nourishments and provided 4,200,000 yd^3 of sand to Folly Beach. Placement area limits identified here were from the original 1993 study.

2.0 REGIONAL GEOLOGY

The coastal zone of South Carolina is situated within the South Atlantic Bight (Georgia Bight), which extends from Cape Hatteras, NC, to West Palm Beach, FL (Davis and Fitzgerald, 2003). This region is characterized by a wide, shallow continental shelf on the trailing edge of the tectonically stable North American Plate. South Carolina's embayed beaches are strongly influenced by the presence of underlying warped and/or faulted basement rock of the Carolina Platform. Overlying these warped basement rocks are Cretaceous to Tertiary strata that form a shelf-ward thickening sedimentary wedge, internally comprised of unconformably bound, on-lapping, and off-lapping units (Horton and Zullo, 1991). Superimposed upon these strata are numerous erosive channeling and scour features caused by fluctuations of sea-level (Schwab et al., 2009). Figure 3 shows a map and cross-section of the regional geological configuration and physiography of the South Carolina coastal margin.

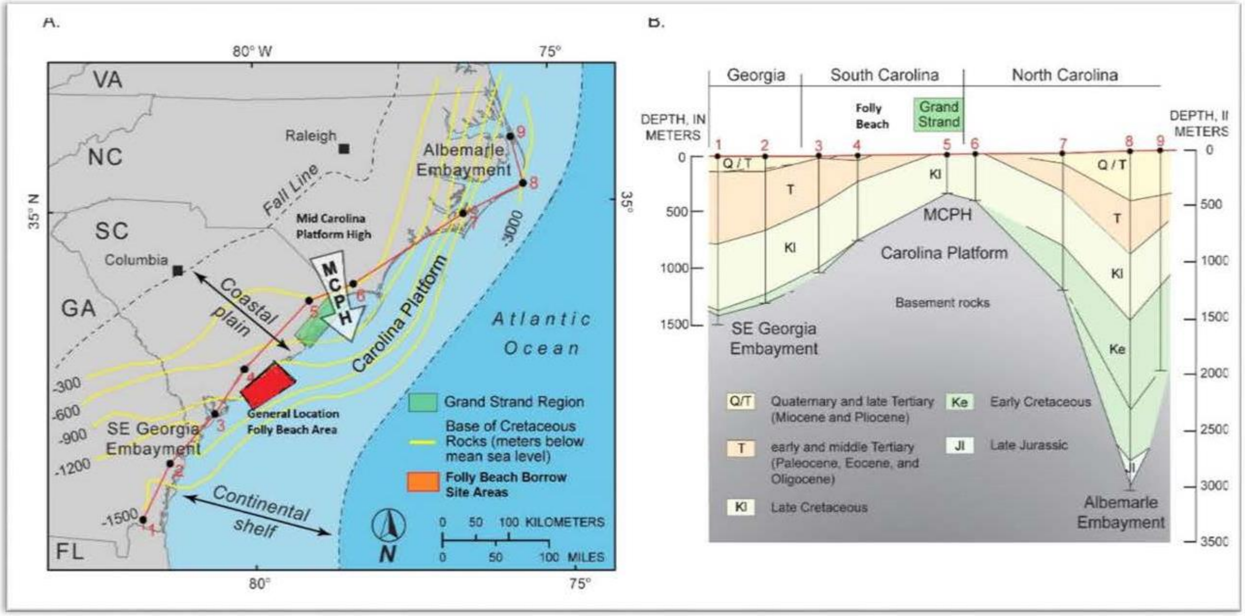

Figure 3. Map and cross-section are showing regional geologic configuration and physiography of South Carolina coastal margin, adapted from Schwab et al. (2009). Yellow lines show structural contours of the basement and inherited influence to stratigraphy.

2.0 STRATIGRAPHIC UNITS

Topographic/bathymetric expression of the landforms indicates that there has been significant shoreline change related to fluctuating sea-level. Stair-stepped marine and estuarine terraces are oriented sub-parallel to the modern shoreline of Folly Beach (Harris et al., 2005). They decrease in elevation seaward from +15.0 meters (49 feet M.S.L.) to -8.0 meters (-26 feet M.S.L.) where the coastal plain merges with the inner continental shelf (Harris et al., 2005).

The major early-Tertiary units are bounded by unconformable surfaces formed by 1) non-deposition or erosion during periods of lowered sea-levels, 2) channel formation and scour associated with seaward migration of the ancient shoreline, or 3) erosional scour along the Tertiary shelf edge (Harris et al., 2005). Internally, these Tertiary formations contain mappable, gently to steeply dipping seismic reflectors and stratigraphically mappable carbonate and phosphate-rich, cemented lag deposits that form ledges offshore, in inlets and river bottoms, and in subaerial exposures on the Coastal Plain (Harris et al., 2005). In contrast, Miocene and Pliocene strata are preserved primarily as broad infill sequences within the lowstand-incised valleys and as isolated local basins on the earlier portions of the system (Katuna et al., 1997; Weems and Lewis, 2002; Harris et al., 2005). Outliers of these Miocene and Pliocene-aged units are scattered throughout the study area as erosional remnants (Weems and Lewis, 2002) and contain variably resistant, scattered strata (Harris et al., 2005).

Quaternary-aged deposits consist of sequences of barrier-island depositional systems that formed as a result of cyclic sea-level highstands (Harris et al., 2005). During lowstands of sea-level, valleys were shallowly incised into the exposed continental shelf and backfilled with various sediment types depending upon local geologic conditions and subsequent sea-level rise and fall rates (Colquhoun, 1969; McCartan et al., 1982; Weems and Lemon, 1993; Harris et al., 2005). Quaternary paleovalleys often consist of muds, sandy muds, and muddy sands while, tidally scoured paleochannels generally consist of clean, shelly sands (Harris et al., 2005).

2.1 FOLLY BEACH GEOMORPHOLOGY

Folly Beach's geomorphology is characterized by linear dune ridges separated by inner swale lows and swamps (Figure 4). The ridges were formed by naturally occurring high sea-level stands over geologic time, beginning about 38,000 years ago (Cleary and Pilkey, 1996). Thus, the most landward ridge set resulted from the locally highest shoreward transgression, with each subsequent ridge set being formed by punctuated lower (or regressed) sea-level stands. These linear ridges continue seaward and make-up some of the past and current borrow sources offshore Folly Beach. For example, depleted borrow areas A through D were constrained to very small linear-like sections which had the same orientation as the linear ridges depicted by the digital elevation model in Figure 4.

The island is situated within a mixed-energy, tide-dominated environment that experiences daily tidal fluctuations >5.0 ft with average significant wave heights of < 2.5 ft (Davis and Fitzgerald, 2003). The amplification of tidal range and small wave heights in this area of the Georgia Bight is caused by a wide and shallow continental shelf coupled with the embayed nature of the South Carolina coastline (Davis and Fitzgerald, 2003). The combination of these factors lead to extensive, inundated marshes in the back-barrier, frequent and large inlets, and "drum-stick" like barrier formation (Davis and Fitzgerald, 2003). Folly Beach is a short barrier island that is separated by Stono Inlet (to the south) and Lighthouse Inlet (to the north). The back-barrier consists of extensive marsh, which extends landward for 2.5 miles before encountering the mainland. Dozens of tidal creeks incise the back-barrier and eventually connect with the flood channels of either Stono Inlet or Lighthouse Inlet (Figure 1). The marsh-filled estuary limits accommodation space, and the development of flood shoals within the back-barrier are infrequent. In contrast, ebb shoals are well established in the Folly Beach nearshore where a low-energy wave climate impacts this depositional environment.

2.2 NATIVE BEACH

Evaluating native beach sand is a vital part of borrow source evaluation and proposed borrow area development. The grain size characteristics of the native beach sand, which are used in the compatibility analyses, are a major factor when assessing the usefulness of a borrow area. Forty-one beach sediment samples were collected and analyzed to determine the native beach grain size characteristics (GDM, 1991). The mean grain diameter of the native beach sand was 2.56 phi (0.17 mm) with a standard deviation of 0.34 phi (0.79 mm), identified as fine-grained sand using the Unified Soil Classification System (USCS). These samples were acquired from the upper beach profile (above the mean low water line[1]). Sediment samples were also acquired below the mean low water line. However, incorporation of these samples results in a finer native mean grain diameter of 2.74 phi (0.149 mm).

[1] MLLW line is equivalent to -3.1 ft NAVD88.

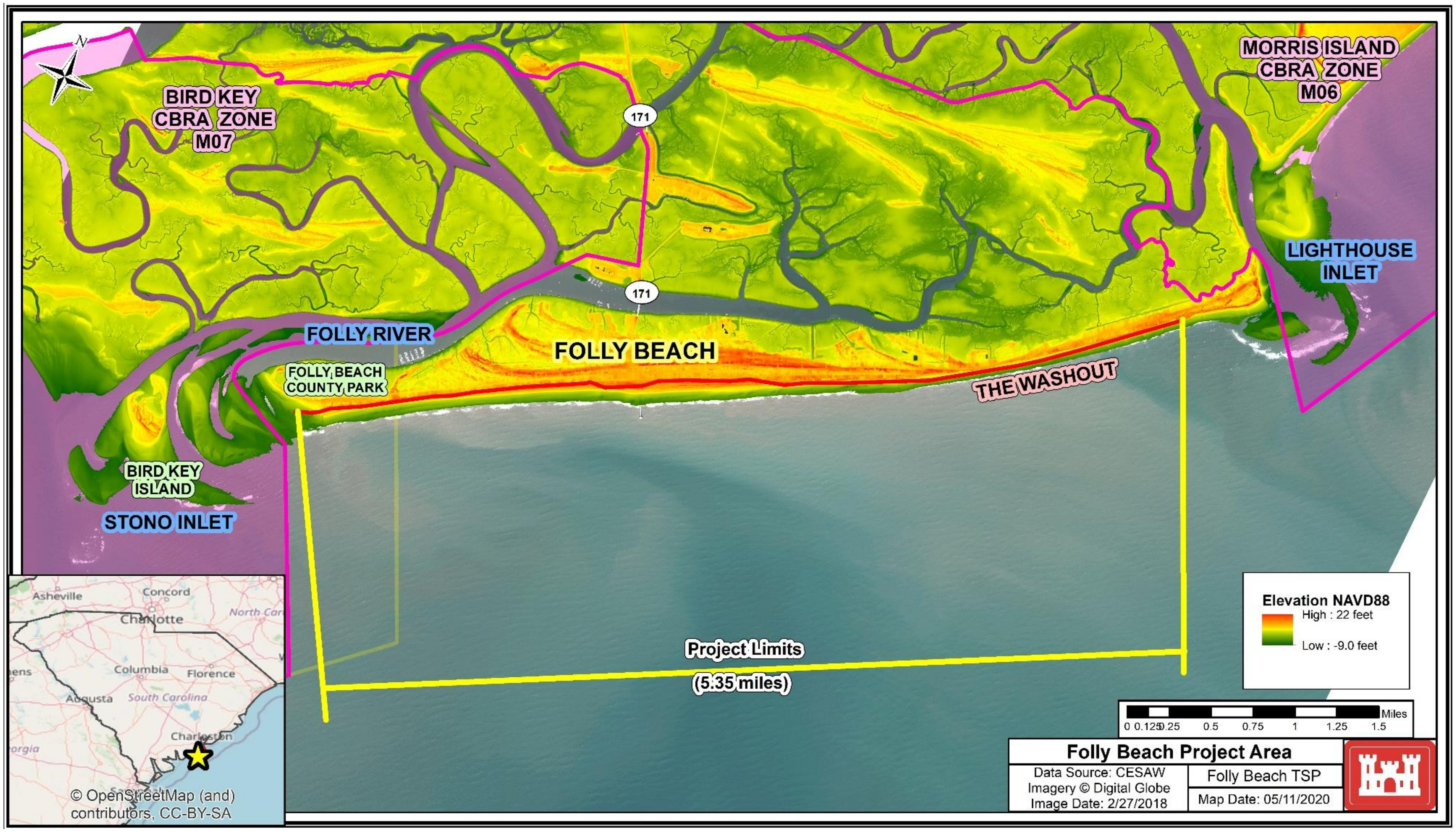

Figure 4. Digital elevation model of Folly Beach from 2016. Cooler colors represent lower elevations while warmer colors represent higher elevations. Notice the linear ridges in the back-barrier (colored by dark orange to red) which likely indicate previous shorelines during higher stands in sea-level.

3.0 PREVIOUS SUBSURFACE INVESTIGATIONS

Over the last three decades, significant geophysical and geotechnical work has been performed offshore Folly Beach. Hundreds of miles of geophysical data, which include single-beam, back scatter, seismic, and multi-beam surveys, coupled with over 600 vibracores, were utilized to depict past and future borrow sources offshore Folly Beach (Figure 5). The next two sections describe the history of all subsurface investigations which led to the delineation of previously authorized offshore borrow areas (A through D).

3.1 GEOPHYSICAL SURVEYS

In 1995, 2000, and 2002, the United States Geological Survey (USGS), Coastal Carolina University (CCU), and Charleston District (SAC) initiated a cooperative effort to complete a comprehensive geophysical mapping survey of the inner continental shelf of Folly Beach (Schwab et al., 2002). This survey was designed to provide regional reconnaissance on the character of surficial deposits in the vicinity of Folly Beach, and to aid the United States Army Corps of Engineers (USACE) in identifying potential sand sources needed for planned storm damage reduction programs. Approximately 700 km of geophysical data collection included side-scan sonar, sub-bottom profiling, backscatter, and precision single-beam bathymetry. Large areas of the inner shelf offshore Folly Beach were found to exhibit high-backscatter (light grey to white) response, a result which was interpreted to represent a rocky substrate or coarse shell hash unlikely to yield sufficient volumes of sand (Gayes et al., 1995). Areas of low-backscatter response are generally indicative of sand or relatively finer grain surficial sediment (Gayes et al., 1995) and these areas were targeted as potential sand sources. Because these areas cannot be further delineated into sand or fine-grained sediment bodies with backscatter alone, subsurface sediment sampling (vibracores) and grain size analyses were completed.

In summary, the collaborative effort from the USGS, CCU, USACE, and the city of Folly Beach covered an extensive area detailing the subsurface nearshore and offshore Folly Beach. Additional single-beam surveys were collected in various areas offshore Folly Beach, mainly in areas where dredging has occurred (borrow areas A, B, C, and D). In 2015, a single-beam survey was conducted seaward of the state’s territorial seas limit[2] and in alignment with Stono Inlet. Following the 2015 survey, two additional single-beam surveys and one multi-beam survey were performed in 2019 landward of the state's territorial seas limit in areas where vibracores from 2019 were collected.

3.2 HISTORICAL VIBRACORE EXPLORATION

Several geotechnical investigations targeted potential offshore borrow areas. Since 1994, a total of 641 vibracores have been collected offshore Folly Beach (Table 2). Twenty-four vibracores were collected in the nearshore by USGS vessels, NURC and FERREL in 1994. Coastal Science and Engineering (CSE) performed ten vibracores in 2002 near the state’s territorial seas limit and 15 in 2012 located in the Folly River. In 2006, USACE Wilmington District performed 71 vibracores

[2] State’s territorial seas limit is also referred to as the three nautical mile line.

within borrow area B using the vessel Snell. Athena Technologies completed a total of 521 vibracores in 2003, 2004, 2005, 2015, 2016, and 2019. Borrow areas A, B, C, and D were investigated by Athena in 2003 and 2004 with a total of 36 and 55 vibracores, respectively. In 2005, Athena completed 55 vibracores in borrow area A. From 2015-2016, Athena collected 170 vibracores in the offshore, 40 vibracores within Stono Inlet, and 25 vibracores in the Folly River. Finally, in 2019 Athena performed 130 vibracores in the nearshore Folly Beach area and 10 vibracores offshore Sullivan's Island. Details of each investigation are found in the following paragraphs of this section.

Table 2. Summary of 1994 to 2019 Vibracore Investigations

Year	Agency	General Location	Number of Vibracores
1994	USGS	Nearshore Folly Beach	24[3]
2002	CSE	State's Territorial Seas Limit	10
2003	Athena	Borrow Areas: A, B, C, D	36
2004	Athena	Borrow Areas: A, B, C, D	55
2005	Athena	Borrow Area A	55
2006	USACE	Borrow Area B	71
2012	CSE	Folly River	15
2015	Athena	Folly Beach Offshore	170
2015	Athena	Stono Inlet	40
2015/2016	Athena	Folly River	25
2019	Athena	Nearshore Folly Beach	130
2019	Athena	Sullivan's Island	10
			641

[3] Cores collected did not contain laboratory data and only visual descriptions were determined for each vibracore. Due to the age of the vibracores and lack of grain size data, these vibracores were not used in the sand isopach created for Folly Beach in Figure 6 and other sand isopachs that could contain vibracores from 1994.

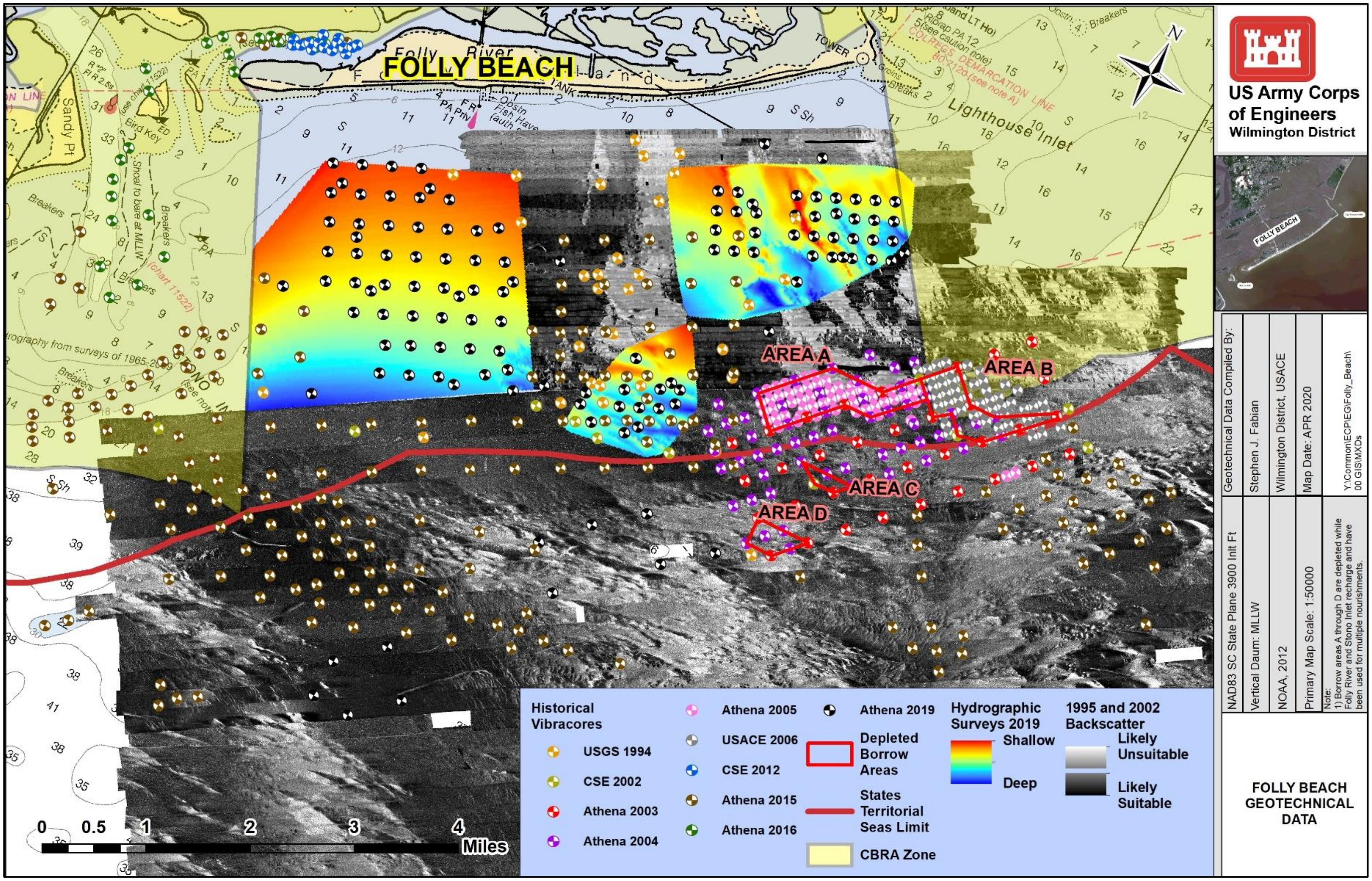

Figure 5. Collective geotechnical information offshore Folly Beach, including: geophysical surveys such as single-beam, multi-beam, and back scatter surveys as well as hundreds of vibracores collected between 1994 to 2019. The southwestern survey area ranges in depths -16 to -30 ft, the middle survey area ranged in depths -21 to -34 ft, and the northeastern survey area ranged in depths from -13 to -24 ft.

In 1994, the USGS selected 24 vibracore locations based on geophysical data obtained in 1991. Selections targeted areas with potentially usable sand for nourishment activities. All of these vibracores were within the state's territorial seas limit but had variable spacing. Collection areas ranged from Stono Inlet to Lighthouse Inlet. In the absence of grain size data, visual descriptions on the core logs were used to determine which locations had the potential for beach compatible material.

In 2002, CSE utilized the visual descriptions from the 1994 vibracores and conducted a small sand search that extended from Stono Inlet to Lighthouse Inlet. Vibracores straddled the state's territorial sea limits line. The ten vibracores collected varied in sand thicknesses from 0.0 to 7.5 ft, with only half having greater than 3.0 ft of usable sand. The vibracores with greater than 3.0 ft usable sand thickness were found to be in and around presently depleted borrow areas A, B, C, and D.

In 2003, an additional sand search was performed by Athena to collect 36 vibracores. The vibracores were spaced 2,000 ft apart and were collected across borrow areas A, B, C, and D. This was a general sand search and, although it did not meet design level criteria for dredging, it narrowed the development of these four borrow sources to be used for future nourishments (e.g. 2005, 2007, and 2014). The vibracores varied in usable sand thicknesses from 0.0 to 8.4 ft. Although the mean thickness of the 36 vibracores was 1.5 ft, higher thicknesses (> 4.0 ft) were present within borrow areas A through D.

Immediately following the 2003 vibracore collection, another phase of vibracore collection occurred in 2004. A total of 55 vibracores were collected by Athena and thicknesses varied from 0.0 to 10.0 ft with a mean thickness of 2.0 ft. Spacing between the vibracores varied but were generally 1,000 ft apart. This period of collection showed that beach compatible sands were present within borrow areas A through D. However, two more vibracore efforts were executed to reach design level.

In 2005, Athena collected 55 vibracores with 500 ft spacing within borrow area A. Sand thicknesses in borrow area A varied from 0.0 to 14.8 ft with a mean thickness of 4.7 ft. Following the completion of this geotechnical effort, borrow area A was utilized for nourishment in 2005 placing approximately 2,338,000 yd^3 on Folly Beach.

Following the 2005 nourishment, another vibracore effort was performed in 2006 across borrow area B. Athena collected 71 vibracores with 500 ft spacing. Sand thicknesses within borrow area B ranged from 0.0 to 5.3 ft with a mean thickness of 1.6 ft. Then in 2007, 486,000 yd^3 of material was placed on Folly Beach from borrow area B. Lastly, the combined borrow areas of A, B, C, and D were used for one final nourishment in 2014 placing 1,419,385 yd^3 which resulted in depletion of these borrow areas.

In between the 2007 and 2014 nourishment, the city funded its own vibracore effort and collected 15 vibracores in the Folly River. In 2012, the city contracted CSE to determine the thickness of usable sand within the Folly River. The spacing of the vibracores was less than 500 ft apart and sand thicknesses ranged from 2.4 to 11.1 ft with a mean sand thickness of 7.3 ft.

The largest single vibracore effort, comprised of 235 vibracores, from 2015 to 2016. The cost of this effort was split due to restrictions from the Coastal Barrier Resources Act (CBRA) of 1982[4], which prohibited the use of Federal dollars for scientific investigations in CBRA zones. Therefore, USACE and the city of Folly Beach split the cost of this investigation, where the city of Folly Beach covered vibracore expenses inside CBRA and USACE covered vibracore expenses outside of CBRA. USACE performed 170 vibracores outside the CBRA zone from Stono Inlet to Lighthouse Inlet. Three primary areas were cored to delineate borrow sources. These three areas were offshore Stono Inlet (beyond the state's territorial seas limit), central Folly Beach (within state's territorial limit), and seaward of depleted borrow areas A, B, C, and D. The make-up of these three areas ranged in sand thicknesses from 0.0 to 14.7 ft with a mean sand thickness of 4.2 ft. The city of Folly Beach then conducted a total of 65 vibracores within the inlet throat and ebb shoals of Stono Inlet and Folly River. The make-up of these three areas ranged in sand thicknesses from 0.0 to 20.1 ft with a mean thickness of 8.2 ft.

The last vibracore effort was performed in 2019 by Athena. A total of 140 vibracores were collected updrift of Stono Inlet, offshore central Folly Beach (within the state's territorial seas limit), downdrift of Lighthouse Inlet (within the state's territorial seas limit), and offshore Sullivan's Island. These described areas will be further discussed in sections 5.0 and 6.0.

4.0 COMPATIBILITY ANALYSIS

Before looking at the individual borrow areas, it is important to understand the differences between field classification and laboratory classification. Field classification of a sample consists of estimating grain sizes in hand, in addition to qualitatively recording sample moisture, plasticity, and other attributes such as mineralogy, cementation, or the presence of shells. Laboratory classification is performed according to ASTM (American Society for Testing and Materials) Standards, D-421 and D-422, to identify the range of grain sizes and weight percentage of each grain size relative to the entire sample. In this process, the sample is physically broken up twice in a mortar using a rubber-covered pestle, after which the sample is placed in a stack of sieves which are used to separate the different grain sizes. The stack of sieves is shaken vertically and horizontally for several minutes.

While the laboratory data are used for performing compatibility analysis, it would be irresponsible to presumptively value these data over that which is gathered with field classifications. The field classifications more closely represent the condition of the material insitu, the same condition in which the material will ultimately be dredged. While the dredging process disturbs in-situ material, there is no evidence to suggest that dredging would physically alter it as much as laboratory preparation. Additionally, field classifications allow for the identification of friable limestone or other indurated or partially indurated grains, which laboratory analysis might classify as being SW or SP. Therefore, for the purpose of beach nourishment, materials field classified as cemented or as gravels are not being considered. Consideration of minimum sand thickness for constructability and economic viability is also

[4] The Coastal Barrier Resources Act (CBRA, Public Law 97-348) was passed by Congress in 1982 to address issues associated with coastal barrier development. CBRA designated various underdeveloped coastal barriers to be ineligible for both direct and indirect federal expenditures and financial assistance, which are believed to encourage development of fragile, high-risk, and ecologically sensitive coastal barriers.

important. In terms of constructability, the minimum thickness required is a function of the type of dredge being utilized. Typically, a hopper-style dredge is the most capable at dredging thin veneers of material (less than 2.0 ft). However, it is uncommon to dredge material less than 2.0 ft in thickness simply because it isn't economically viable in most cases.

The need to maintain a vertical buffer between suitable beach fill material and unsuitable beach fill material is important during the dredging process. In most of the 2-D fence diagrams which include proposed dredge cuts, it is apparent that the maximum dredge depths are shallower than the depth of suitable beach fill material. This is the result of suitable beach fill material being underlain by material that is unsuitable. The vertical buffer is required to help prevent dredging of unsuitable material, which may occur from errors of vertical placement of dredging equipment. The thickness of the vertical buffer depends on a combination of engineering judgment and the character of underlying material. For example, a clean sand (SP) with 4 percent fines (passing the #200 sieve) underlain by a silty sand (SM) with 13 percent fines (passing the #200 sieve) would warrant a vertical buffer of 0.5 ft, due to the fact that if some of the silty sand ended up on the beach it would likely not be a significant problem. Conversely, if the same clean sand were underlain by poorly graded gravel (GP) a much larger vertical buffer would be warranted, such as 2.0 ft. Generally, for this project, vertical buffers range from 1.0 to 2.0 ft.

Following the collection of the 2019 vibracores, a sophisticated compatibility analysis was performed to determine future borrow sources to be used for nourishment. Beach nourishment success depends on finding a source of sand that is similar in character to the native beach. Three scenarios, described by Dean (1991; 2002), are possible:

- Borrow area sediment is finer than the native beach-resulting in excessive sand migration offshore and flattening of the beach profile.
- Borrow area sediment is coarser than the native beach-resulting in higher "stand-up" of fill material and a steeper beach profile through the surf zone.
- Borrow area sediment matches the native beach-the placed fill material will follow existing surface contours, mimicking the existing profile.

Particle-size analysis was conducted on the majority of the vibracore samples in accordance with ASTM Standard D 422, "Standard Test Method for Particle-Size Analysis of Soils" using the following U.S. Standard sieve sizes: 3/4", 3/8", No. 4, No. 7, No. 10, No. 14, No. 18, No. 25, No. 35, No. 45, No. 60, No. 80, No. 120, No. 170, No. 200, and No. 230[5]. In addition to the particle-size analysis, all samples were classified using visual engineering soil classification in accordance with ASTM Standard D 2487, "Classification of Soils for Engineering Purposes" (Unified Soil Classification System, (USCS) Table 3), as required in Engineering Manual 1110-1-1804.[6]

The first step in delineating potential borrow areas was determining the mean and median composite grain sizes and percent fines (passing No. 200 sieve) for each vibracore. This consists of a weighted average of the grain size characteristics within the "suitable" portion of the

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[5] Particle-size analysis was not conducted for 1994 vibracore collection.
[6] All vibracore logs, descriptions and respective laboratory data can be found here: Y:\Common\ECP\EG\Folly_Beach\04 BORINGS

vibracore. A portion of material considered to be "suitable" for beach-fill may consist of Poorly Graded Sand (SP), Poorly Graded Sand with Silt (SP-SM), Silty Sand (SM), Poorly Graded Sand with Clay (SP-SC), and Clayey Sand (SC) per the USCS, as long as the portion of material meets the following criteria:

- Less than 10 percent, by weight, material passes #200 sieve over weighted average;
- Less than 10 percent, by weight, material retained on the #4 sieve over weighted average;
- Material retained on the 3/4 inch sieve does not exceed, by percentage or size, which is found on the native beach;
- Contains no construction debris, toxic material, or other foreign matter; and
- Contains no cemented sands or rock fragments.

Unsuitable materials encountered in this study consist of SP-SM, SM, SP-SC, or SC not meeting the criteria listed above, as well as, Low Plasticity Silt (ML), High Plasticity Silt (MH), Low Plasticity Clay (CL), and High Plasticity Clay (CH) per the USCS. If there is unsuitable material (>0.5 ft.) that lies on top of the suitable portion, the entire core was excluded due to inaccessibility of the suitable material. After composite grain size analyses, the suitable portion of material within the core was then termed the "usable sand thickness."

Using the criteria described above, a sand isopach was created among the 641 vibracores. Creating the sand isopach identified areas containing suitable sands for beach placement. Nine areas were identified as suitable for beach nourishment. Four of these areas exist within the CBRA zone, and five exist outside of the CBRA zone. After creating the sand isopach, further grain size analyses were done to determine the most suitable sands in each area distinguished. Core composites for all 641 vibracores were performed in order to expand the criteria for beach compatible sands and determine the composite percent fines for each vibracore. Figure 6 shows the thickness of sands containing less than or equal to 10% fines with the core composites overlayed to show the composite percent fines within each vibracore. Further delineation of these borrow sources was performed by determining overfill ratios which will be discussed in section 7.0.

Table 3. USCS definitions (based on ASTM-2487).

Major Division		Group Symbol	Group Name	Criteria
$F_{200}<50$	Gravel $R_4/R_{200}>0.5$	GP	Poorly graded gravel	$F_{200}<5$; $C_u\geq4$, $1\leq C_z\leq3$
	Sands $R_4/R_{200}\leq0.5$	SW	Well-graded sand	$F_{200}<5$; $C_u\geq6$, $1\leq C_z\leq3$
		SP	Poorly graded sand	$F_{200}<5$, Does not meet the SW criteria of C_u and C_z
		SM	Silty Sand	$F_{200}>12$, PI<4
		SC	Clayey sand	$F_{200}>12$, PI>7
		SW-SM	Well-graded sand with silt	$5\leq F_{200}\leq12$, satisfies C_u and C_z criteria of SW and PI>7
		SP-SM	Poorly graded sand with silt	$5\leq F_{200}\leq12$, does not satisfy C_u and C_z criteria of SW and PI<4
		SP-SC	Poorly graded sand with clay	$5\leq F_{200}\leq12$, does not satisfy C_u and C_z criteria of SW and PI>7
$F_{200}>50$	Silts and Clays $LL\geq50$	MH	Sandy silt	≥30% plus No. 200, % sand ≥ % gravel
		CH	Fat clay	<30% plus No. 200, <15% plus No. 200
			Fat clay with sand	<30% plus No. 200, 15-29% plus No. 200, % sand ≥ % gravel

Note: C_u = uniformity coefficient

C_z = coefficient of gradation

LL = liquid limit

PI = plasticity index

F_{200} = percentage finer than the No.200 sieve

R_4 = percentage retained on the No.4 sieve

R_{200} = percentage retained on the No.200 sieve

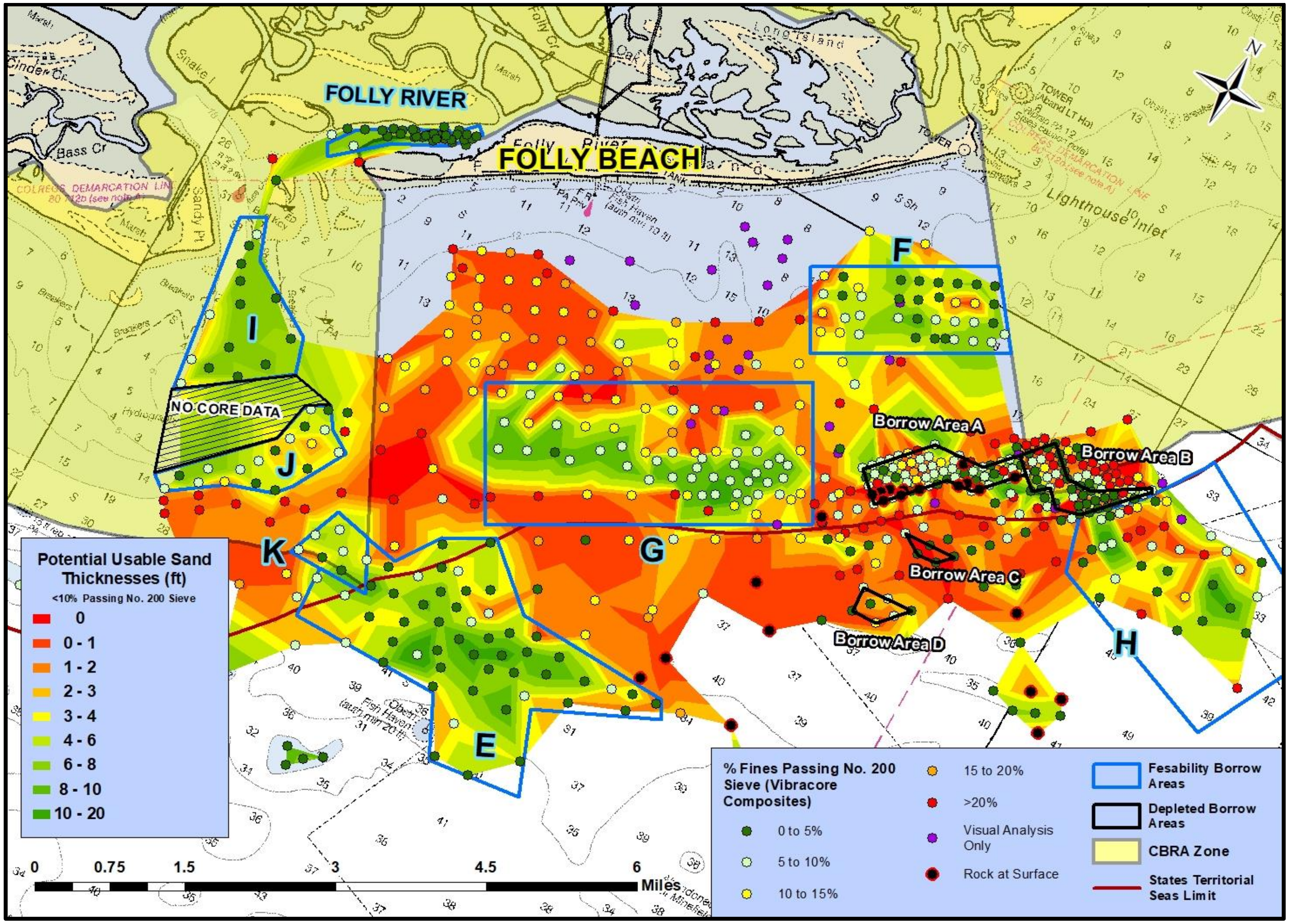

Figure 6. Folly Beach usable sand thicknesses containing less than 10% fines with core composites overlain indicating percent fines within each core. The Sullivan's Island borrow source is not included within this map, but the location is provided within the inset map for reference.

5.0 FEASIBILITY BORROW AREAS OUTSIDE CBRA ZONE

Borrow areas outside CBRA exhibit very fine- to fine-grained sand with intermittent layers of clayey sands, lean and fat clays, and cemented sands/limestone. Thick deposits of widely spread, poorly graded, fine- to medium-grained sands are scarce in this region. Historically, offshore borrow sources A, B, C, and D have provided a mix of suitable and unsuitable beach-fill to Folly Beach. The historical vibracore data collected over the last two and half decades have identified five areas outside the CBRA that could provide adequate beach-fill for Folly Beach. The distance from Folly Beach of these borrow areas range from 1.5 miles to 10.0 miles. Figures 7 to 39 show the usable sand thicknesses, percent of fines, and fence diagrams that depict the geologic framework of each borrow area.

5.1 BORROW AREA E

The location of borrow area E is seaward of the state's territorial seas limit and is approximately 4.0 to 6.0 miles from Folly Beach (Figure 6). Water depths range from -33 to -44 ft NAVD88[7]. Vibracore data are from 2015. Usable sand thicknesses reach up to 15.3 ft and average 5.8 ft. The grain sizes range from 0.18 to 0.62 mm (2.47 phi to 0.69 phi) with an average grain size of 0.22 mm (2.18 phi). Percent fines passing the No. 200 sieve averages 3.8% (Figure 7).

This borrow area is likely the result of relict ebb shoals from Stono Inlet that occurred during a lower stand in sea-level. According to top of hole elevation and nautical charts, this borrow area is made up of a network of troughs and ridges. The ridges contain the greatest usable sand thickness, while the troughs indicate lesser thicknesses of usable sand. The borrow source has a well-defined stratigraphic layer of fine poorly graded sand with intermittent layers (< 0.5 ft) of clay and clayey/silty sands within the poorly graded sand layer. The poorly graded sand layer terminates at -41 ft. Underlying the poorly graded sand layer is a mixture of clayey sand and well-graded gravel that ranges in thickness from 3.0 to 10.0 ft before encountering a high plasticity clay. This clay dips gently to the east southeast, and the top of this strata ranges from -42 to -52 ft (Figures 8 to 13).

5.3 BORROW AREA F

The location of borrow area F is 1.0 to 2.5 miles offshore and is adjacent to Lighthouse Inlet (Figure 6). Water depths range from -12 to -28 ft. Vibracore data are from 1994 to 2019. Usable sand thicknesses reach up to 10.0 ft and average 5.0 ft. The grain sizes in this borrow area range from 0.13 to 0.54 mm (2.94 phi to 0.89 phi) with an average grain size of 0.26 mm (1.94 phi). Percent fines passing the No. 200 sieve averages 5.3% (Figure 14).

Borrow area F is the closest out of all of the borrow sources outside the CBRA zone. The origin of this borrow area is likely tidally influenced paleo-channels that deposited poorly graded sands and clayey sands to this area. The 2019 single-beam survey highlights these geomorphic features and indicates two shore-perpendicular ridge-like features with two troughs straddling either side.

[7] All water depths will be in NAVD88 unless otherwise specified.

These features can be seen in Figures 15 to 19. The largest ridge is in the center of the borrow area and contains the thickest deposits of usable sands. A more subtle ridge is present on the southwestern end with usable thicknesses of 3.0 to 4.0 ft. The troughs within the two ridges show thinner deposits of usable sands with thicknesses of less than 2.0 ft. Depending on the location of the vibracore, the poorly graded sand layer begins at -12 ft and roughly terminates at -23 ft. Within the poorly graded sand layer, there are rip-up clasts and intermittent pockets of clayey and silty sands throughout. Below the poorly graded sand, a high plasticity clay is present in some of the vibracores. This layer ranges from -23 to -27 ft across the borrow area. The majority of the vibracores, with a few exceptions, terminate into clayey sand (Figures 15 to 19).

5.2 BORROW AREA G

The location of borrow area G is 2.0 to 3.5 miles offshore and is located centrally off of Folly Beach (Figure 6). Water depths range from -16 to -33 ft. Vibracore data are from 1994 to 2019, and usable sand thicknesses vary across the borrow source. Usable sands exist in the northeastern and southwestern corners of the borrow area. The grain sizes in this borrow source range from 0.11 to 0.33 mm (3.18 phi to 1.60 phi) with an average grain size of 0.17 mm (2.56 phi). Percent of fines passing the No. 200 sieve averages 7.6% (Figure 20).

Borrow area G is the same distance and orientation as the depleted borrow areas, A and B. In addition, the orientation of the borrow area is similarly positioned to the present-day shoreline of Folly Beach. In all likelihood, these borrow sources could have been a relict shoreline of Folly Beach during a lower stand in sea-level. The quality of sands in this borrow area stretches the limit of usable sand with the majority of the area containing greater than 10% fines. The top 1.0 to 2.0 ft contains fine poorly graded sands underlain by a combination of clayey and silty sands and isolated pockets of poorly graded sands. The majority of the vibracores terminate into clayey sand. However, the most distal fence diagram, F to F’, indicates a layer of high plasticity clay ranging from -36 to -46 ft. Some of the vibracores indicate well-graded gravel with silt and clays that lie atop the high plasticity clay, but it is not continuous across the borrow area (Figures 21 to 46).

5.4 BORROW AREA H

The location of borrow area H is 5.5 to 7.0 miles offshore and is the most northeastern borrow source offshore Folly Beach (Figure 6). Water depths in this area range from -33 to -40 ft. Vibracore data are from 2003, 2005 2006, and 2015. Usable sand thicknesses reach up to 13.4 ft and average 5.1 ft. The grain sizes range from 0.17 to 0.68 mm (2.56 phi to 0.56 phi) with an average grain size of 0.34 mm (1.56 phi). Percent of fines passing the No. 200 sieve averages 4.4% (Figure 29).

This borrow area requires additional vibracore investgation to obtain accurate material volumes and sediment characteristics. Vibracores within this area are spaced greater than 1,500 ft. apart. The material in borrow are H material likely results from relict ebb shoals from Lighthouse Inlet or a relict shoreline, both occurring during a lower stand in sea-level. The most eastern end of borrow area H contains the thickest deposits of usable sands. For this area, the top of hole elevations indicate very subtle, shore-perpendicular, ridge-like features. These areas are where the thicknesses and most suitable sands are present. Vibracores along the ridge indicate 10.0 ft of poorly graded sands while vibracores taken off the ridge-like features indicate a thin veneer of poorly-graded sands, which is atop a low plasticity silt, high plasticity clay, or well graded gravel (Figures 30 to 35).

5.5 SULLIVAN'S ISLAND

The Sullivan's Island borrow area is located 10.0 miles to the northeast of the center point on Folly Beach (Figure 6)[8]. Water depths range from -12 to -15 ft. Vibracore data are from 2019, and usable sand thicknesses reach up to 10.0 ft and average 6.5 ft. The grain sizes range from 0.12 to 0.28 mm (3.06 phi to 1.84 phi) with an average grain size of 0.20 mm (2.32 phi). Percent of fines passing the No. 200 sieve averages 4.7% (Figure 36).

This borrow area is located on the northeastern side of the jetties, which straddle the entrance to Charleston Harbor. Usable sand thicknesses in this area are a result of the northern jetty blocking longshore sediment transport. This causes accretion of fine-grained sands just north of the jetty. The borrow area has a well-defined stratigraphic layer of fine poorly graded sand from -12 to -22 ft with sub-layers (1.0 to 2.0 ft) of clayey/silty sands. Underlying the poorly graded sand layer are fat clays, clayey sands, and silts occurring at various depths. Although this resource contains significant beach compatible sands, the distance to Folly Beach from this borrow area is substantial. Pumping distances could reach up to 12.0 miles in order to cover the length of the authorized project (Figures 37 to 39).

[8] The location of Sullivan's Island borrow area can be found in the Figure 6 inset map (the most northern, rectangular polygon).

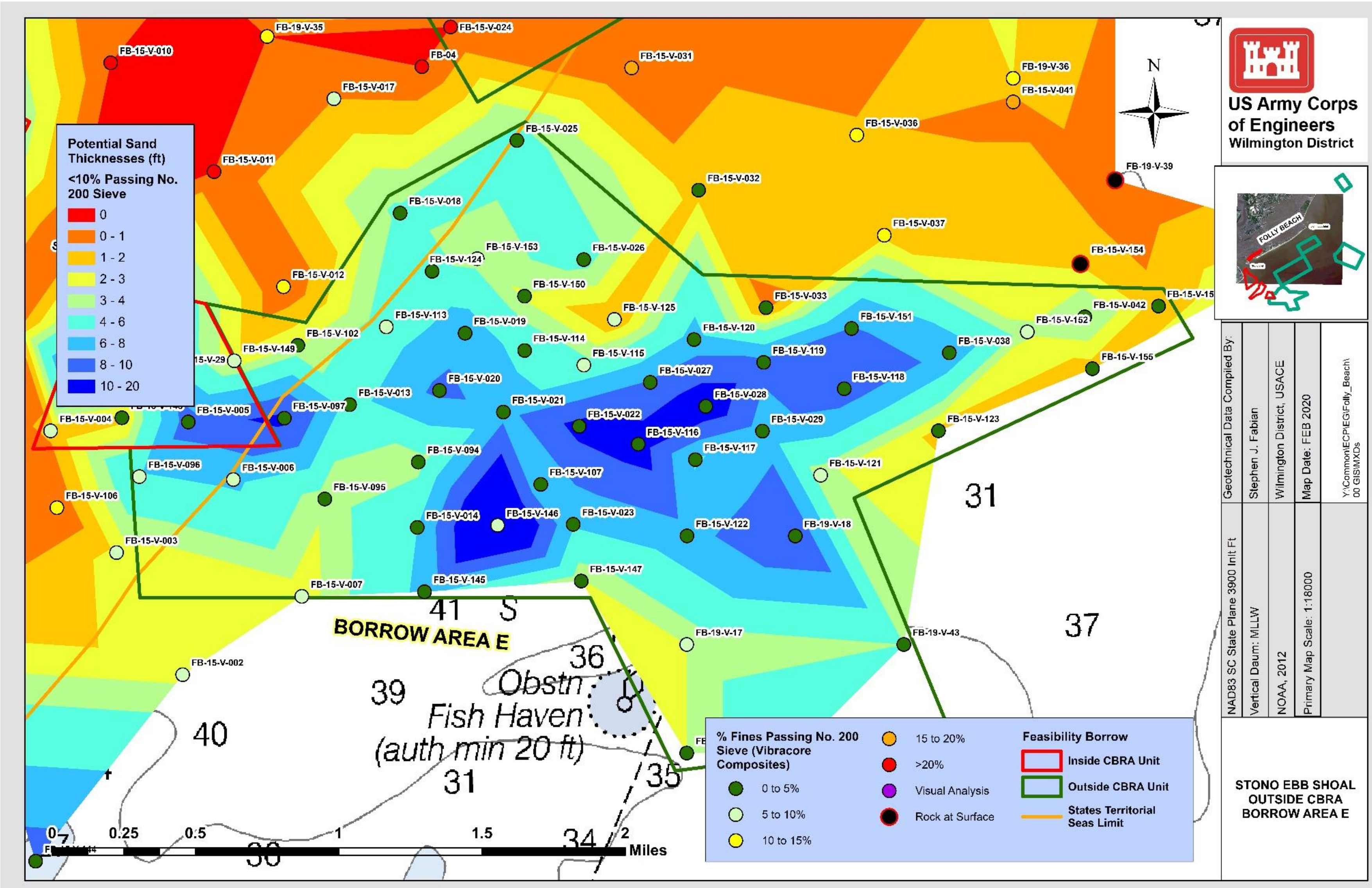

Figure 7. Usable sand thicknesses (ft) within borrow area E.

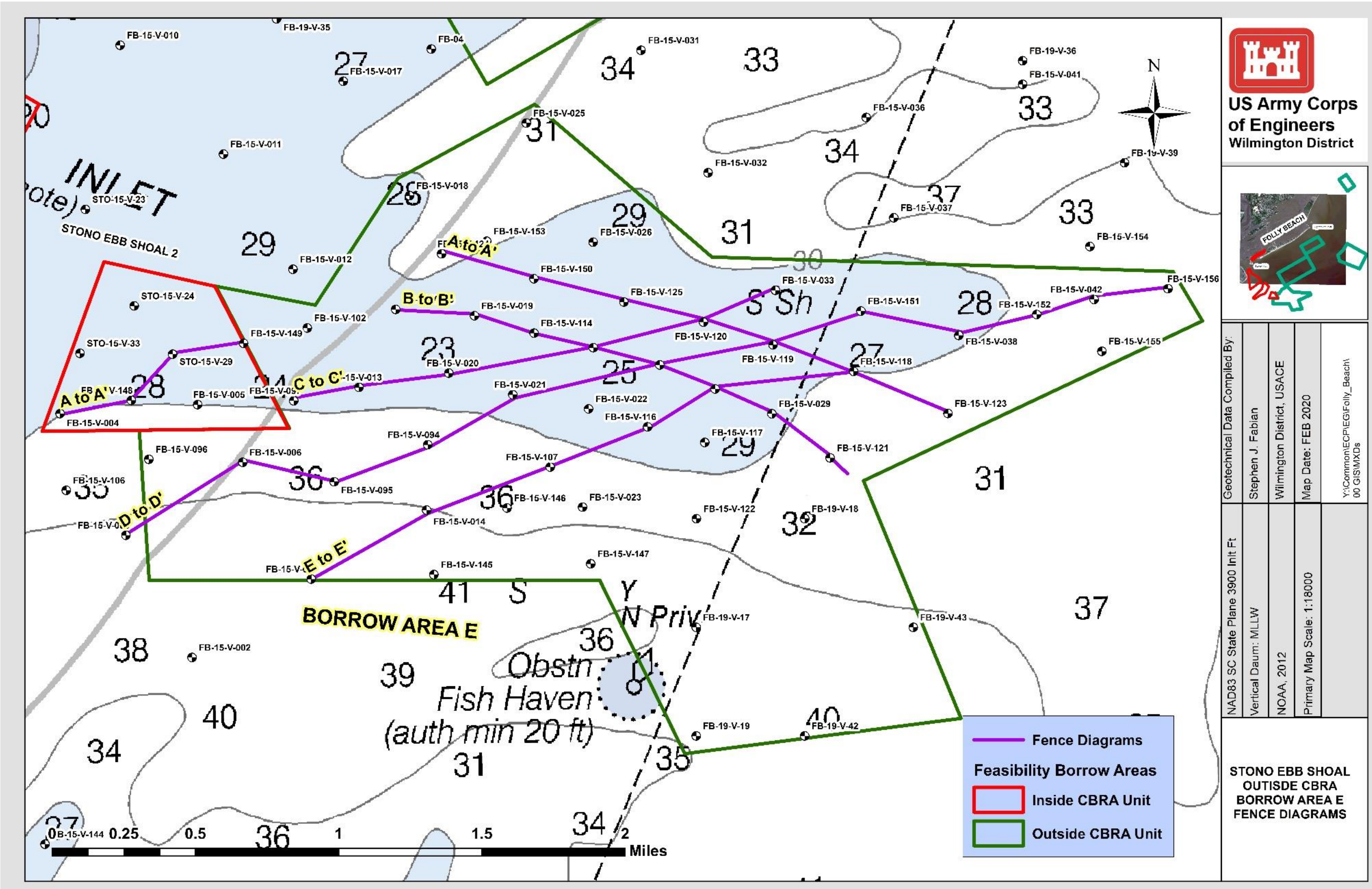

Figure 8. Borrow area E fence diagram locations.

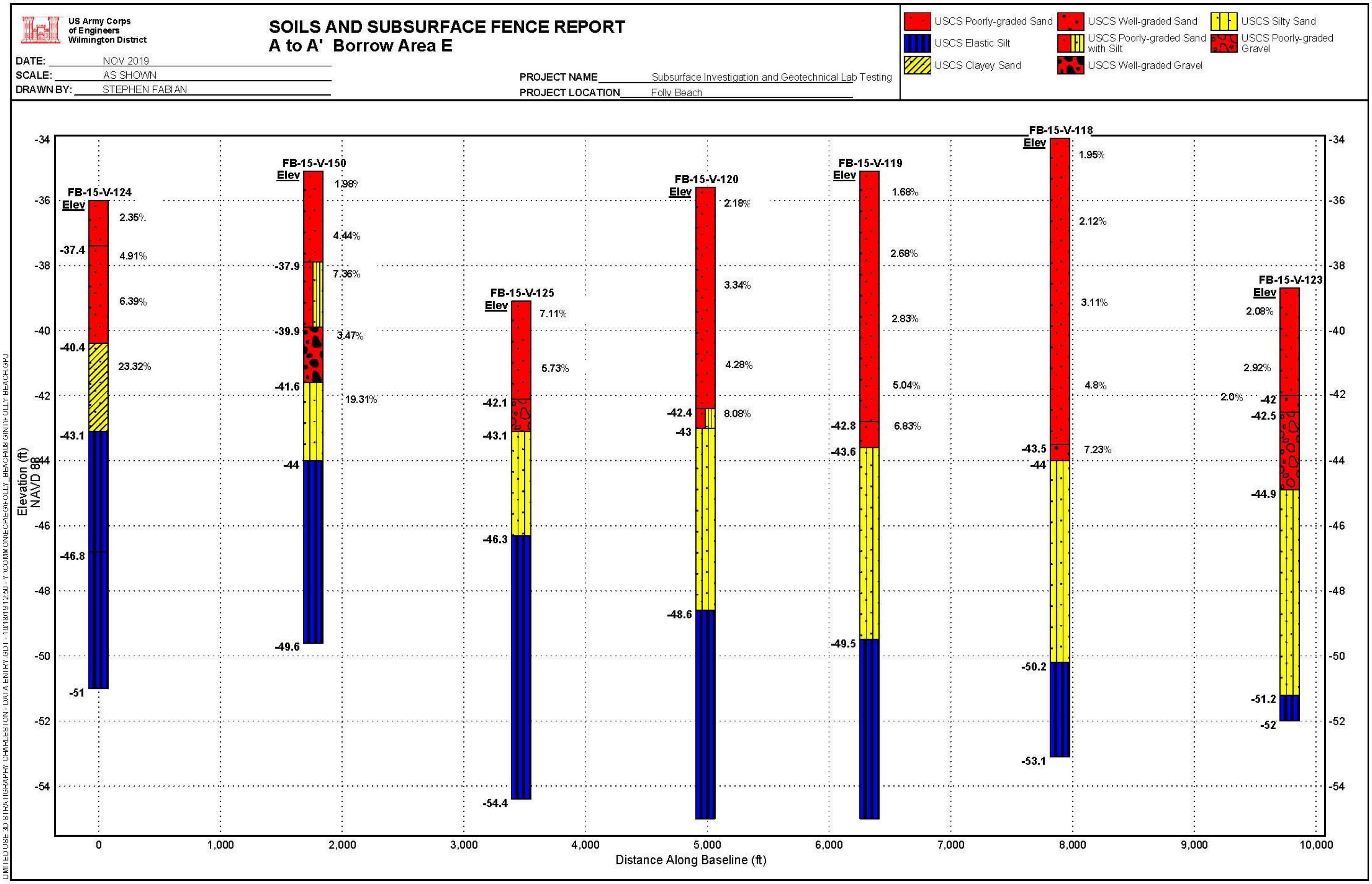

Figure 9. Fence diagram: A to A' borrow area E.

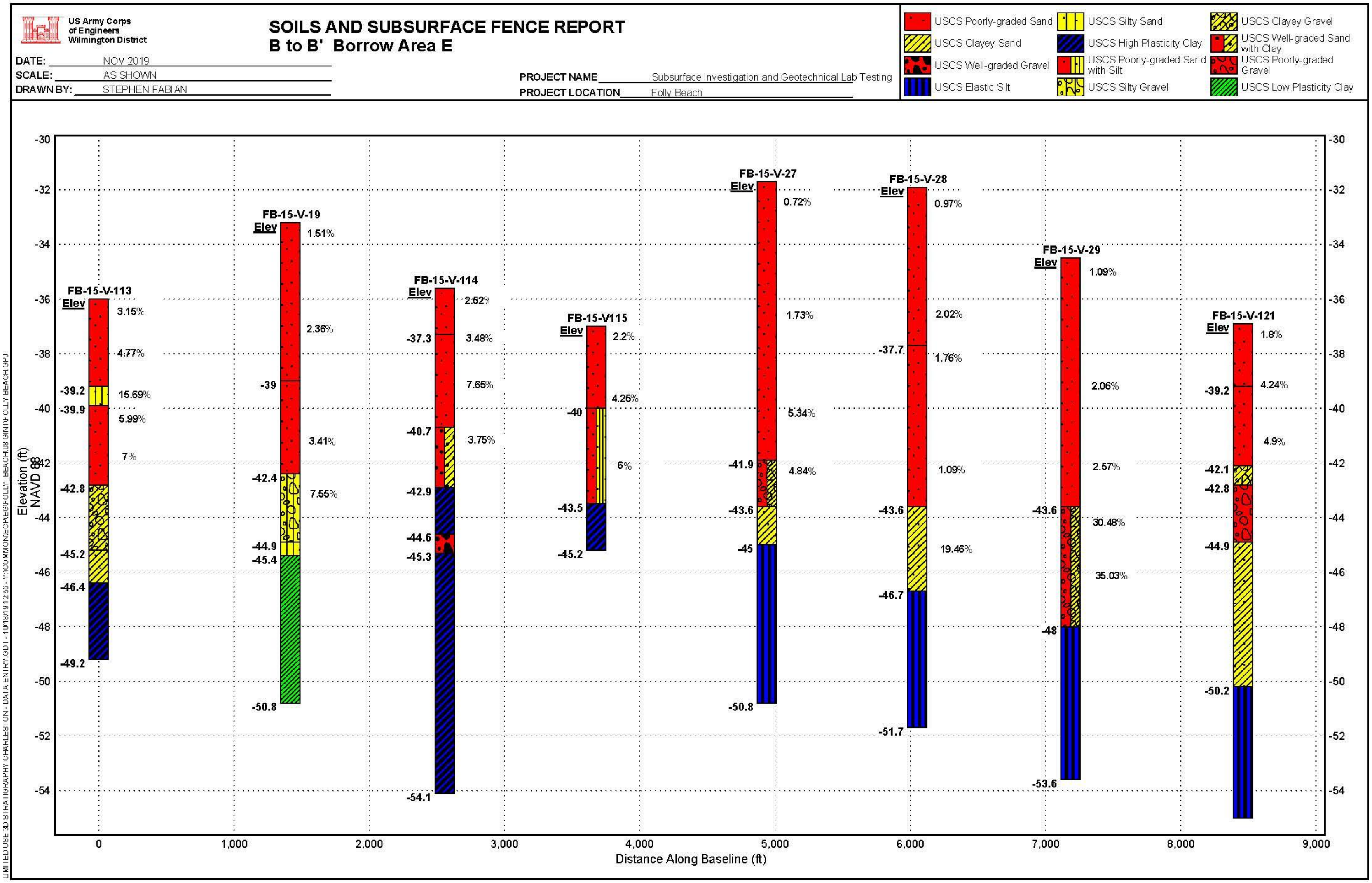

Figure 10. Fence diagram: B to B’ borrow area E.

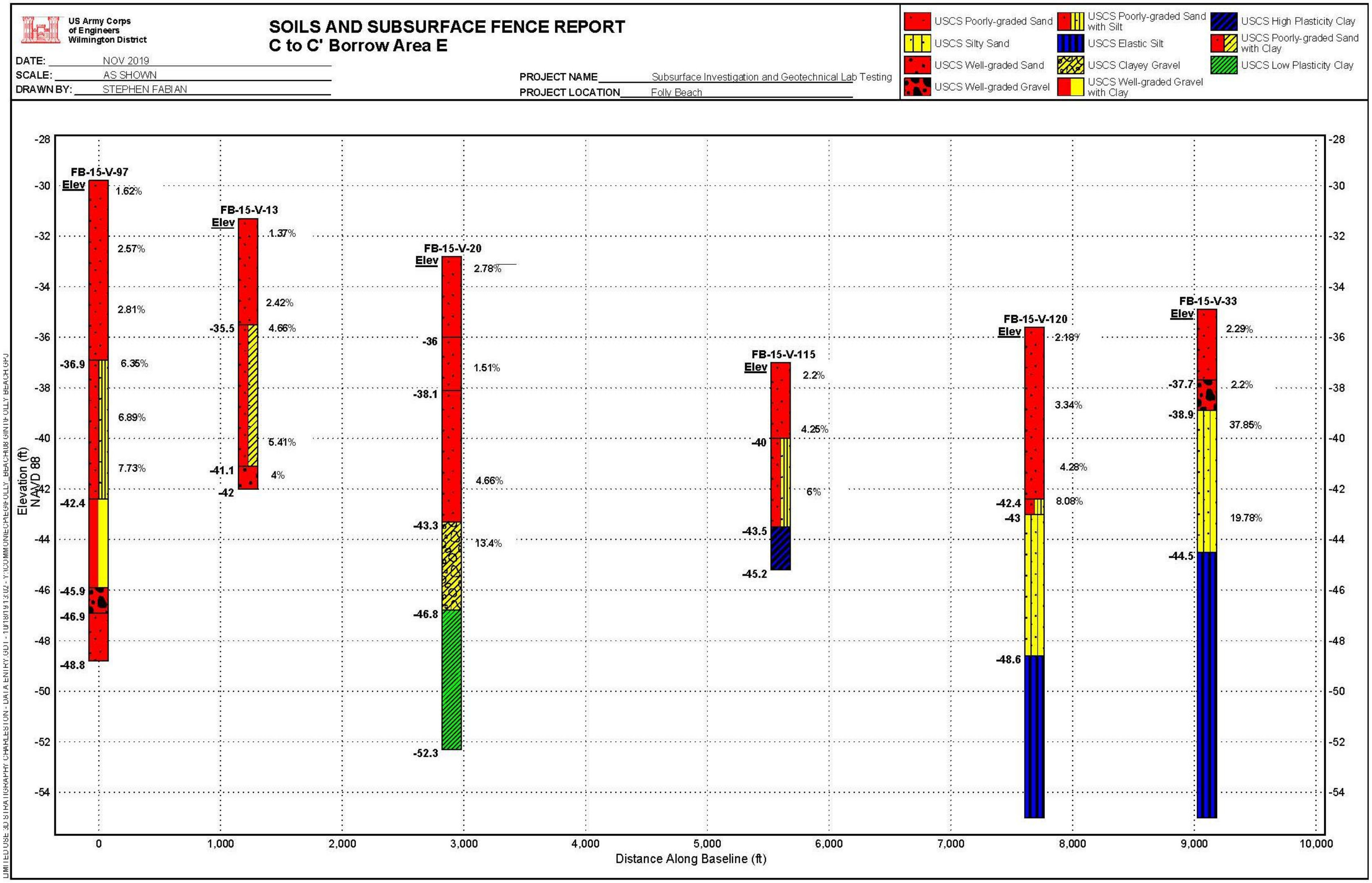

Figure 11. Fence diagram: C to C' borrow area E.

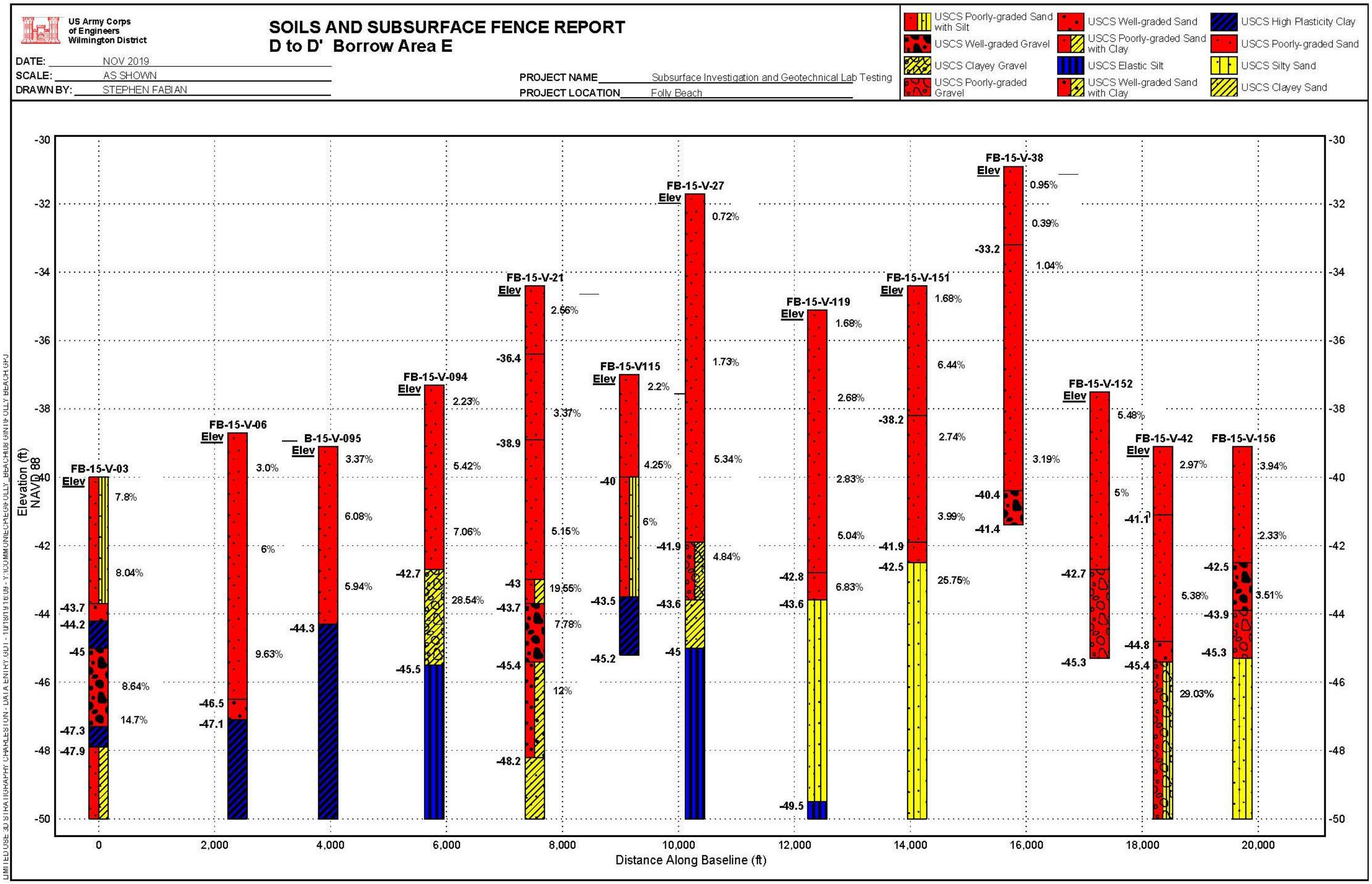

Figure 12. Fence diagram: D to D’ borrow area E.

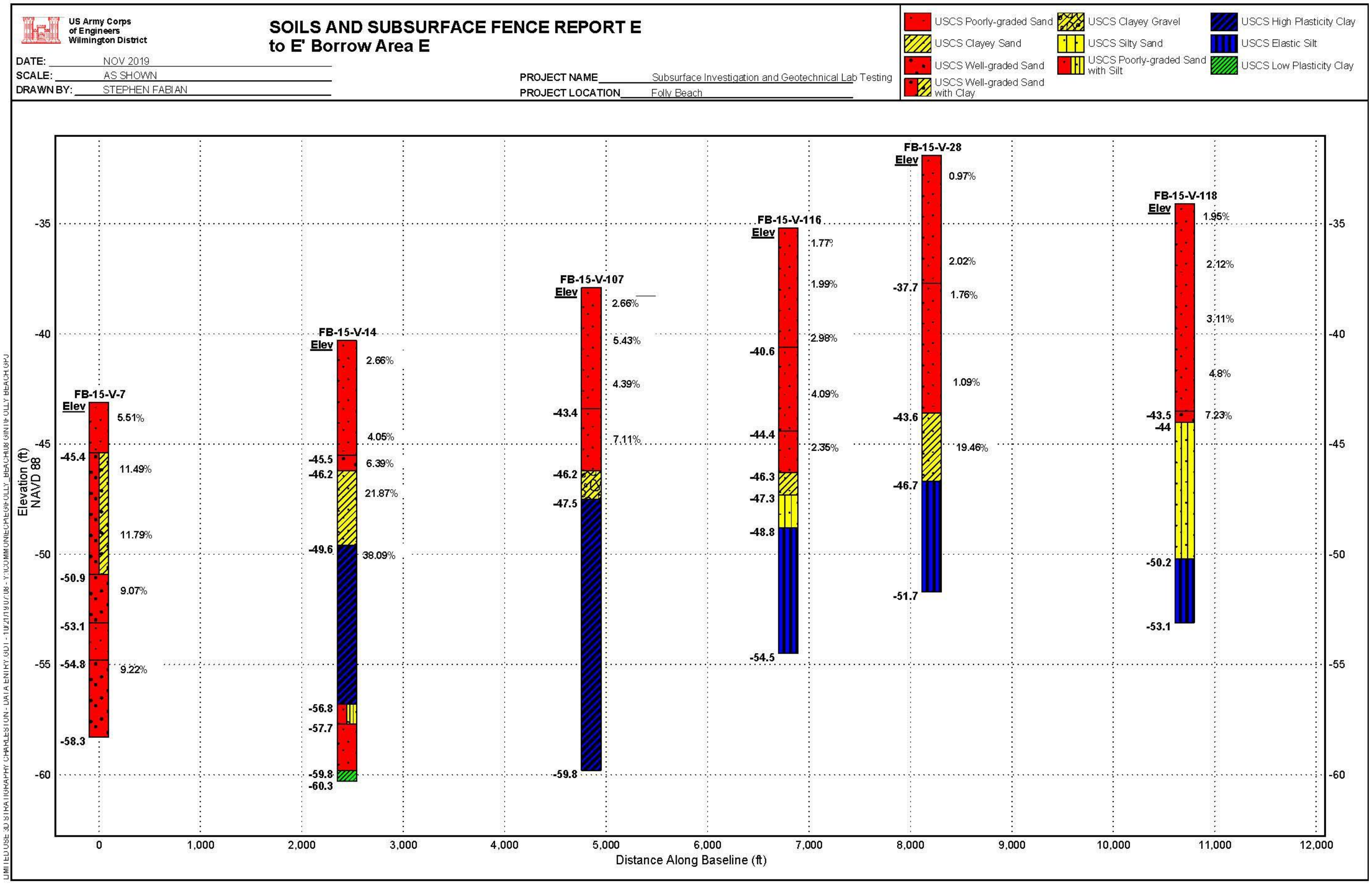

Figure 13. Fence diagram: E to E’ borrow area E.

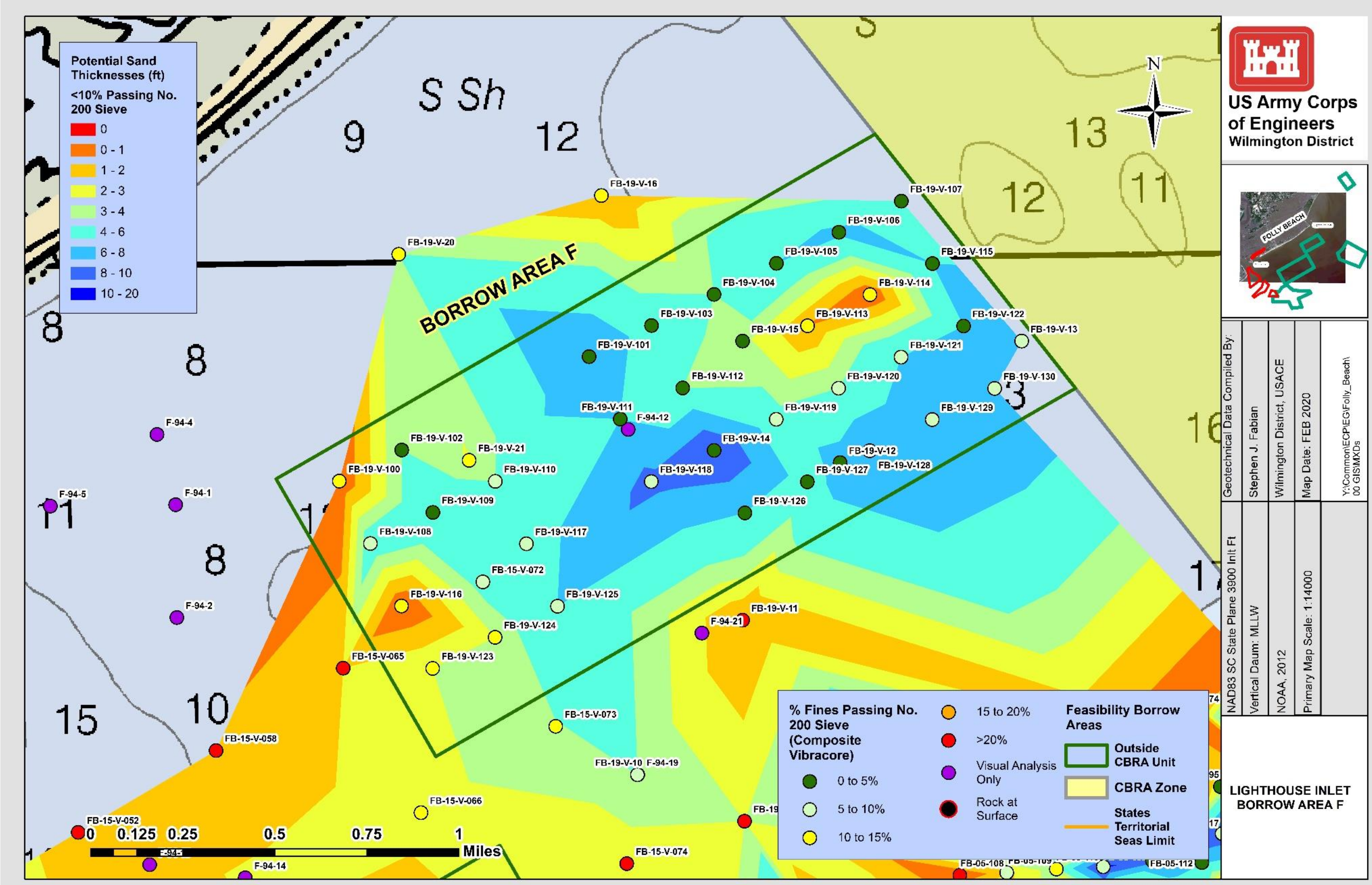

Figure 14. Usable sand thicknesses (ft) within borrow area F.

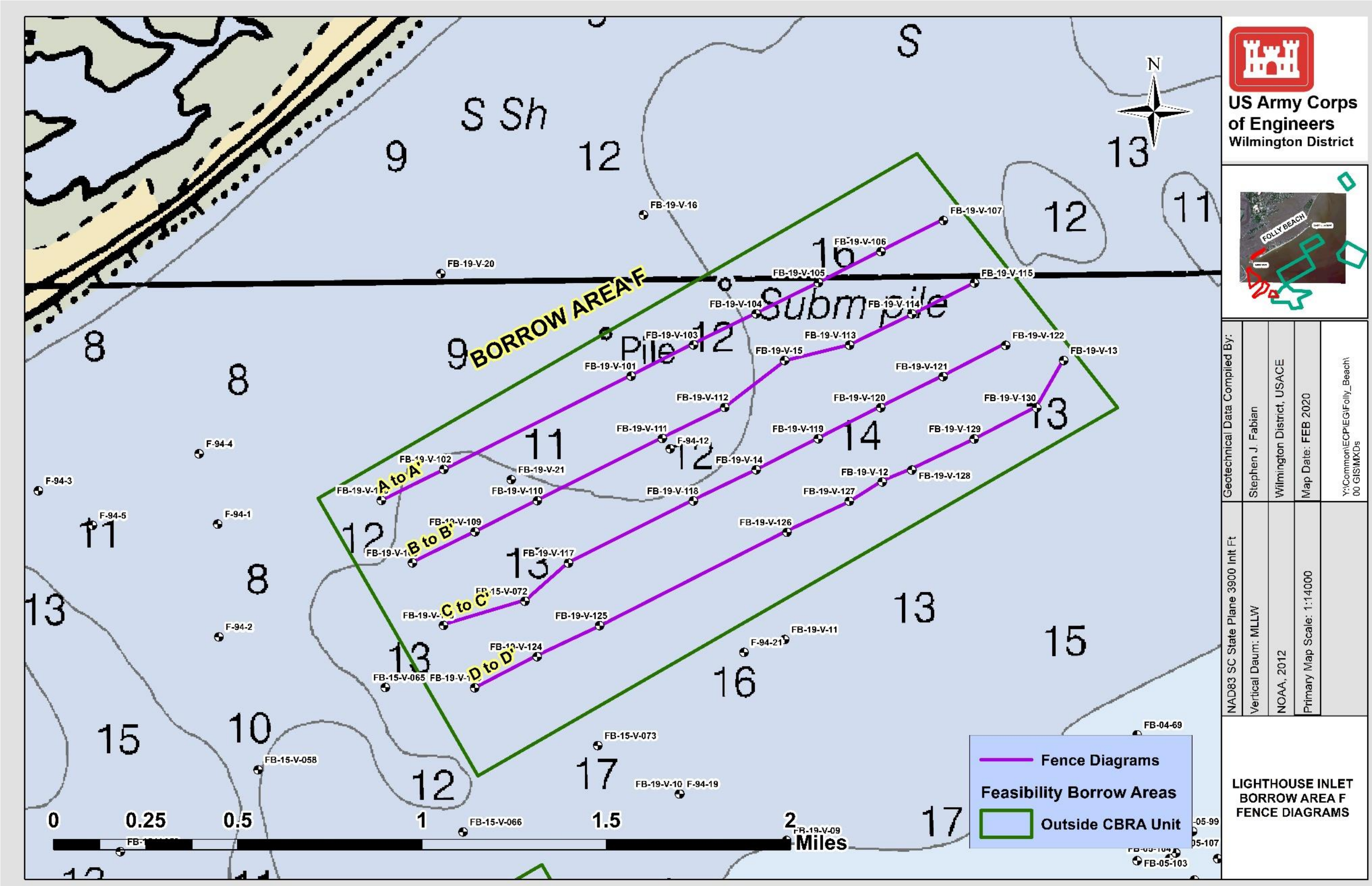

Figure 15. Borrow area F fence diagram locations.

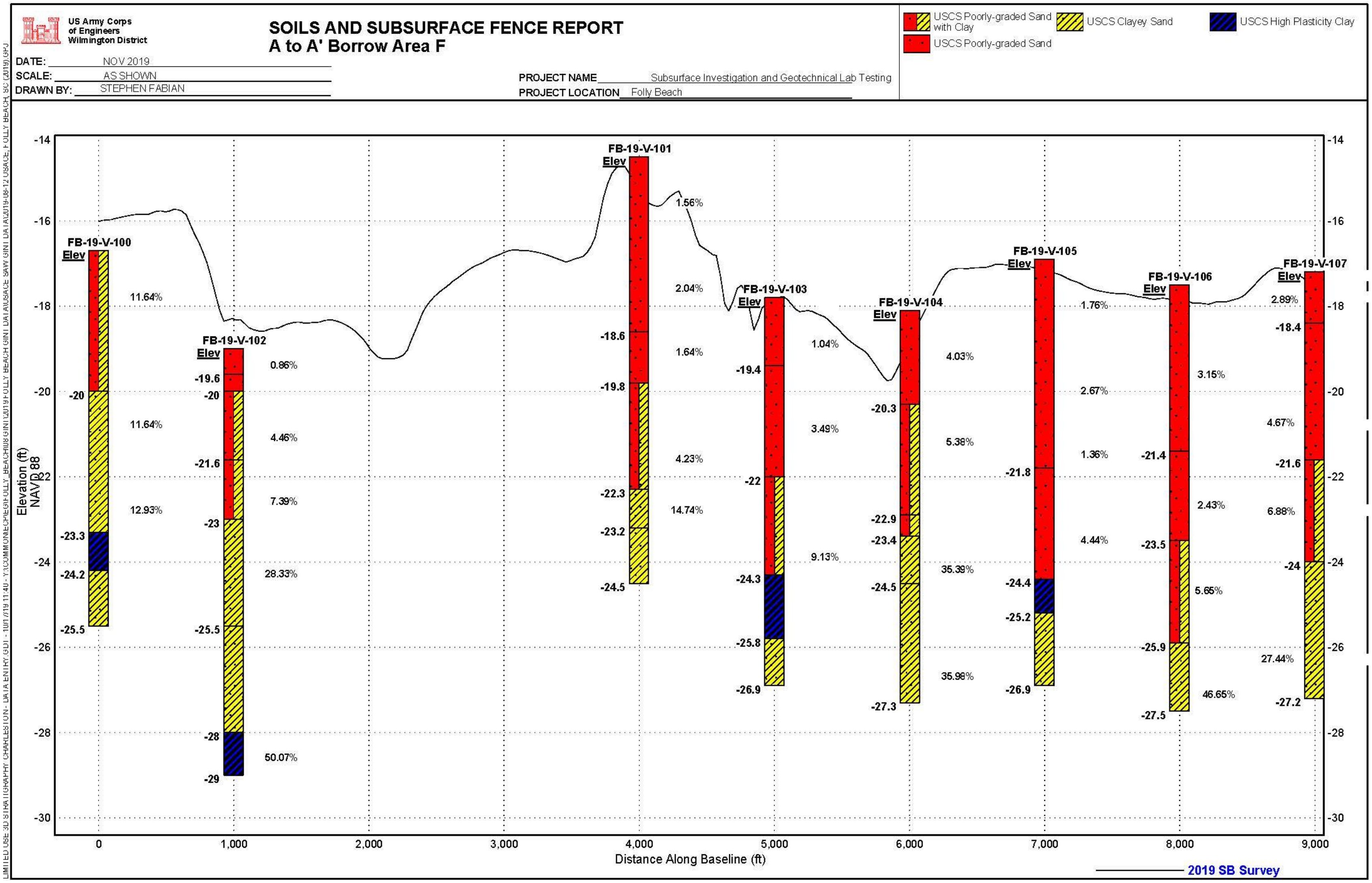

Figure 16. Fence diagram: A to A' borrow area F.

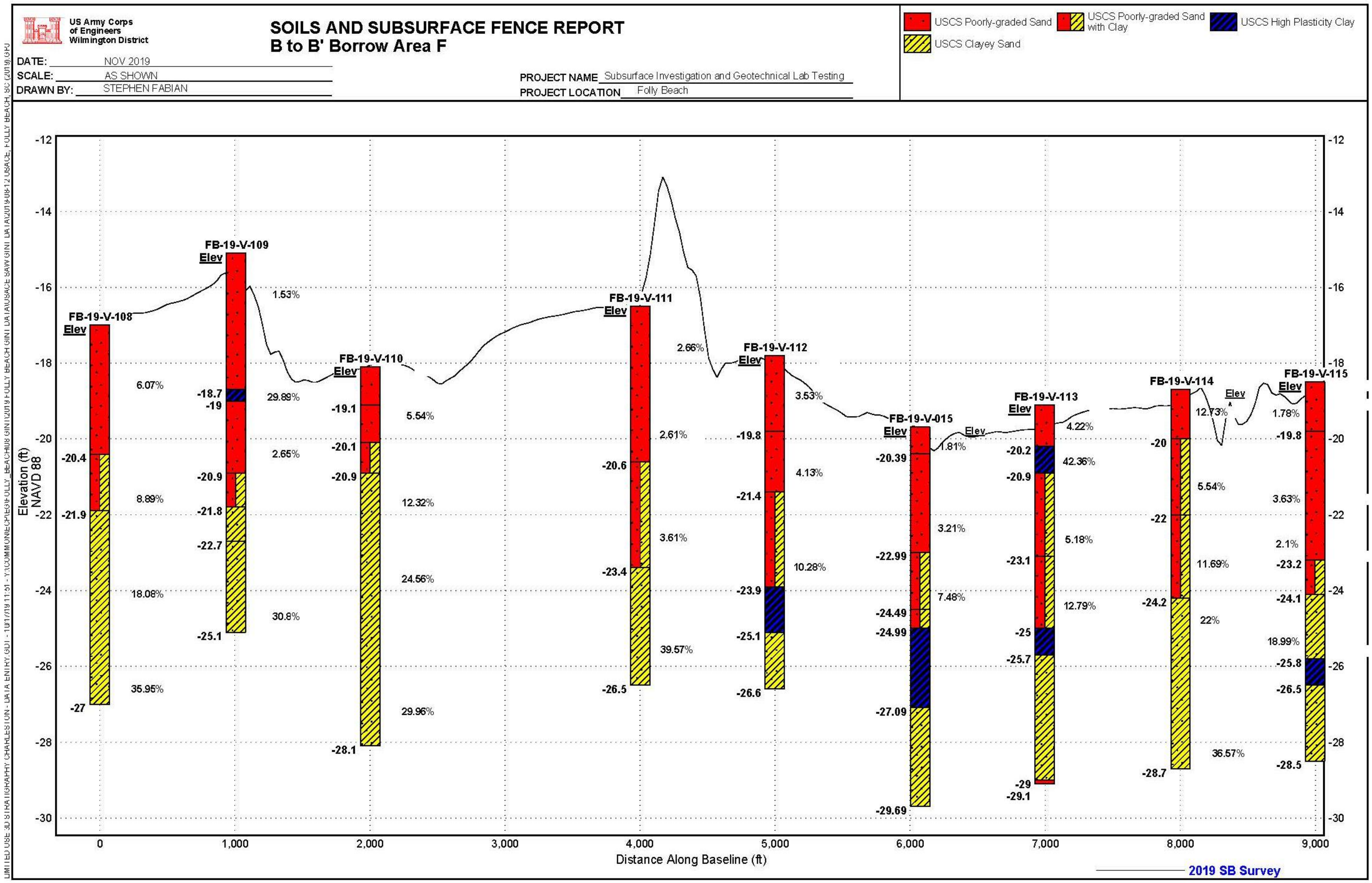

Figure 17. Fence diagram: B to B' borrow area F.

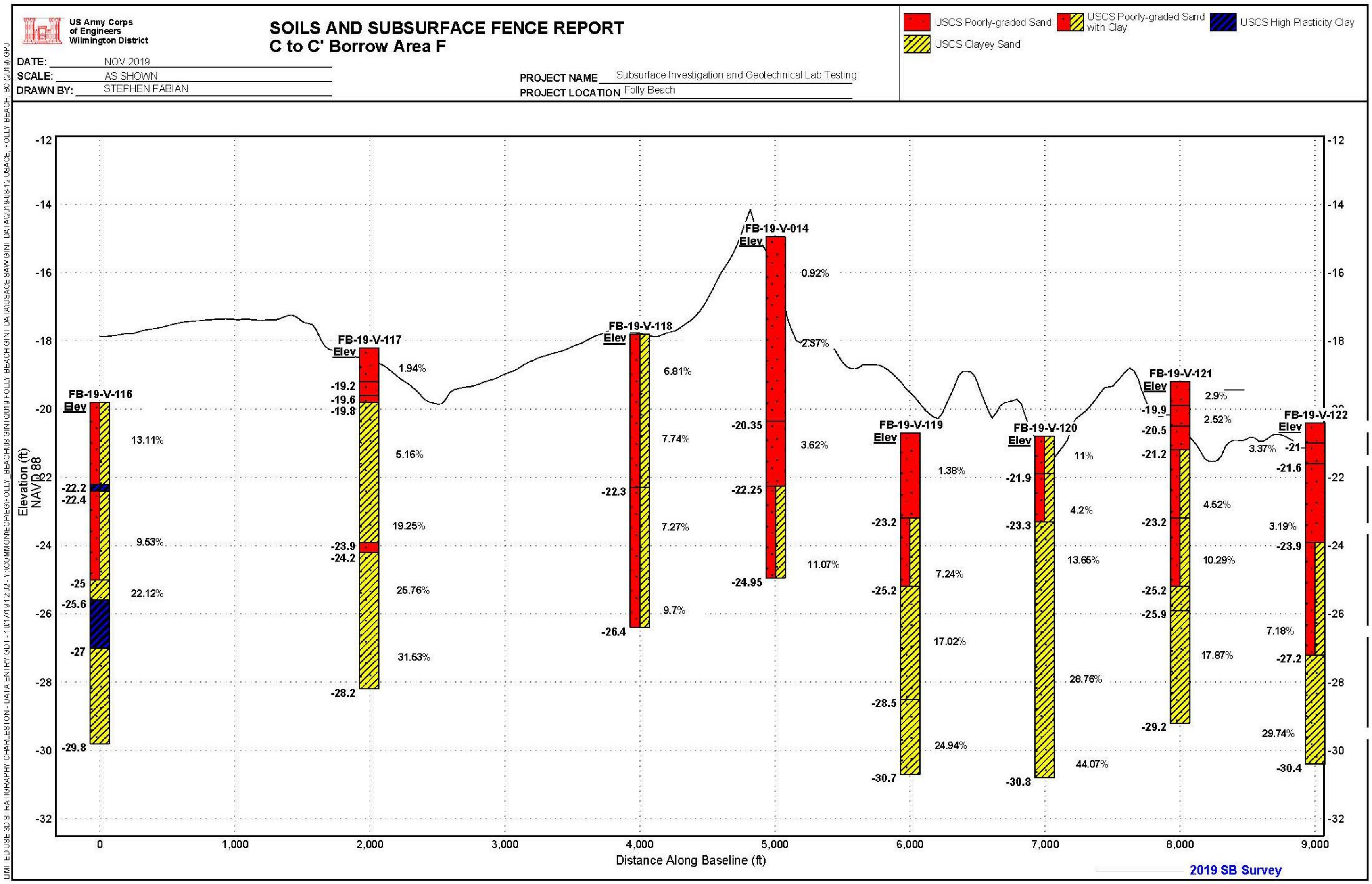

Figure 18. Fence diagram: C to C' borrow area F.

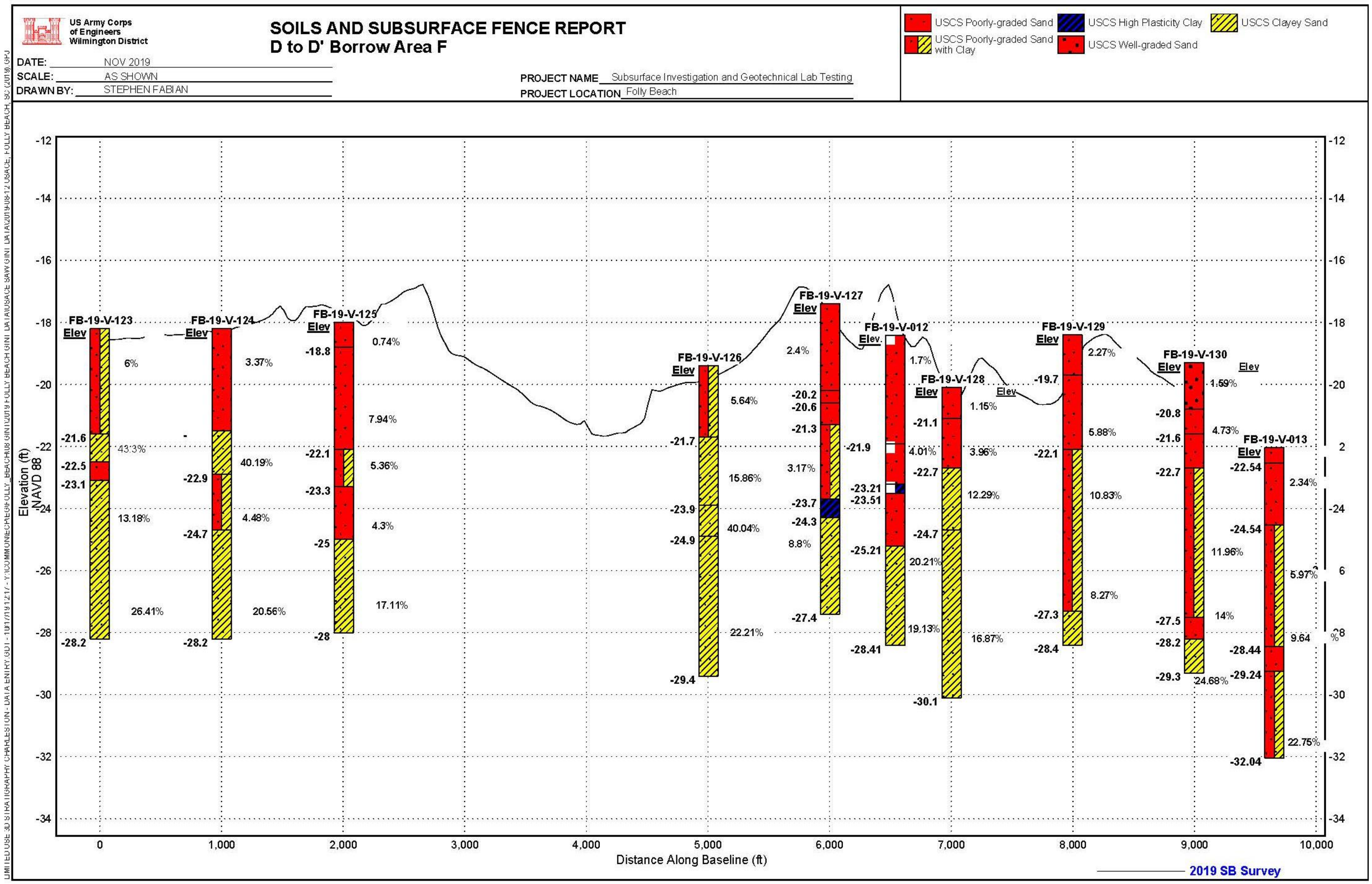

Figure 19. Fence diagram: D to D’ borrow area F.

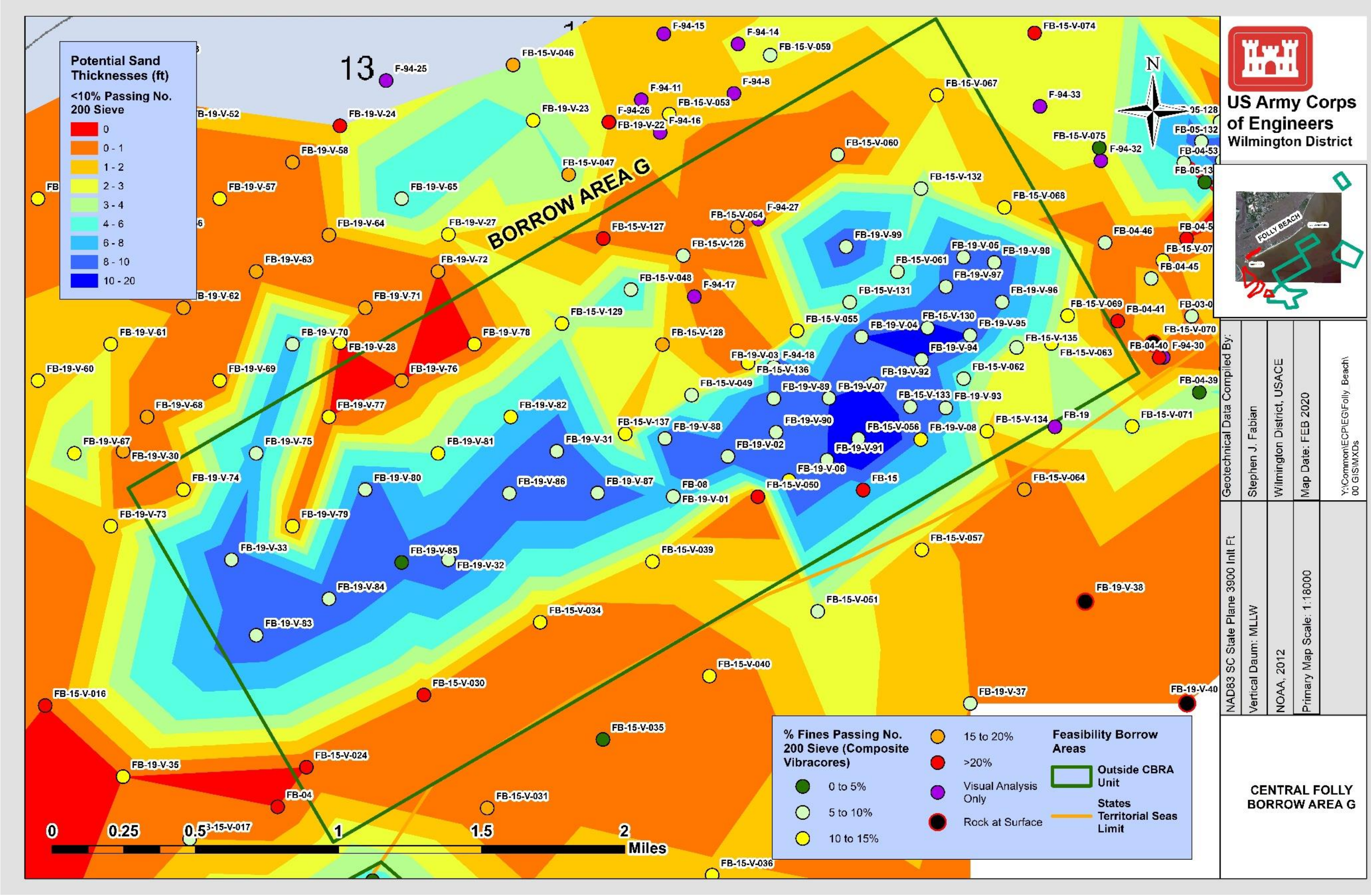

Figure 20. Usable sand thicknesses (ft) within borrow area G.

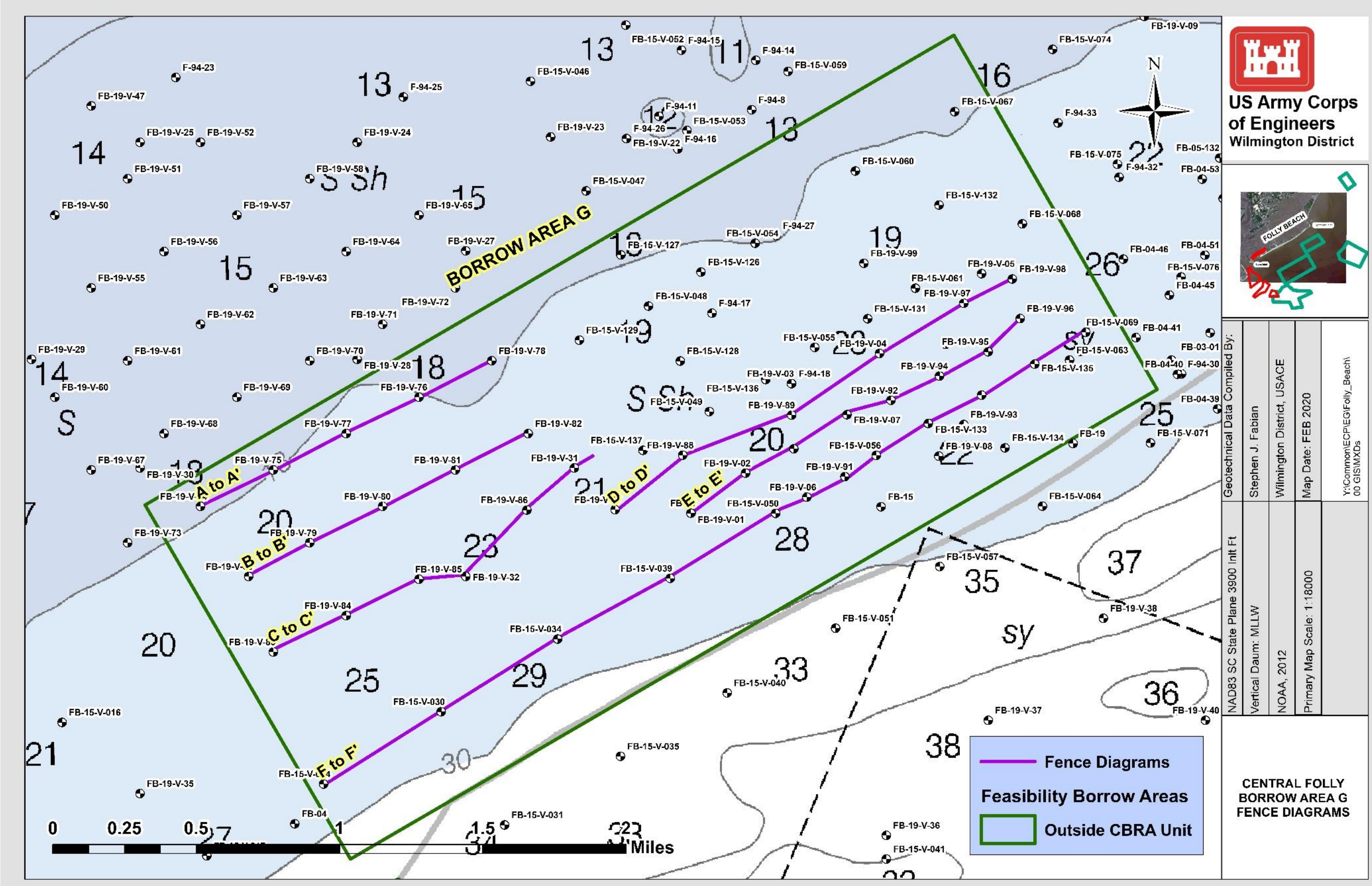

Figure 21. Borrow area G fence diagram locations.

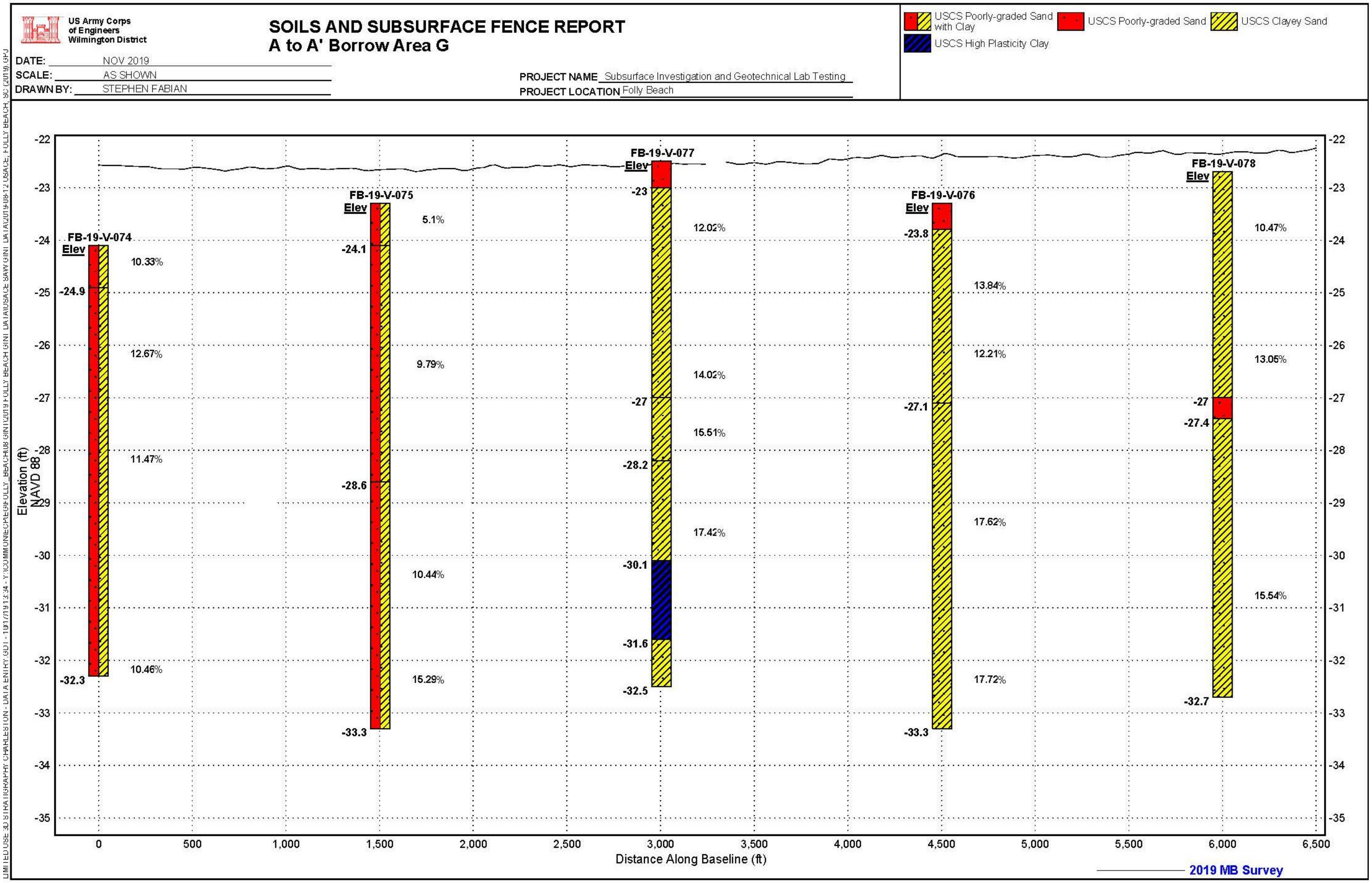

Figure 22. Fence diagram: A to A' borrow area G.

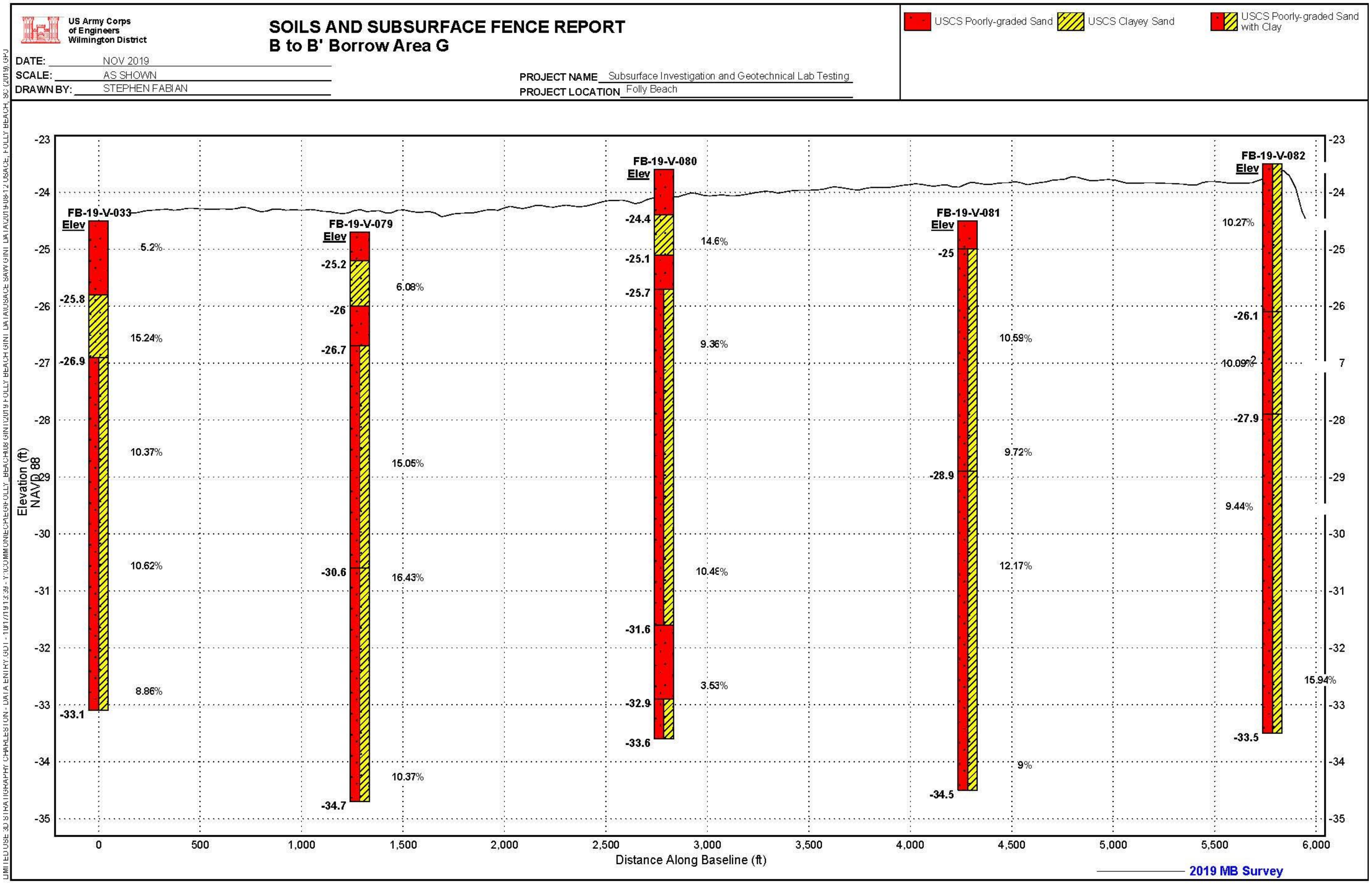

Figure 23. Fence diagram: B to B' borrow area G.

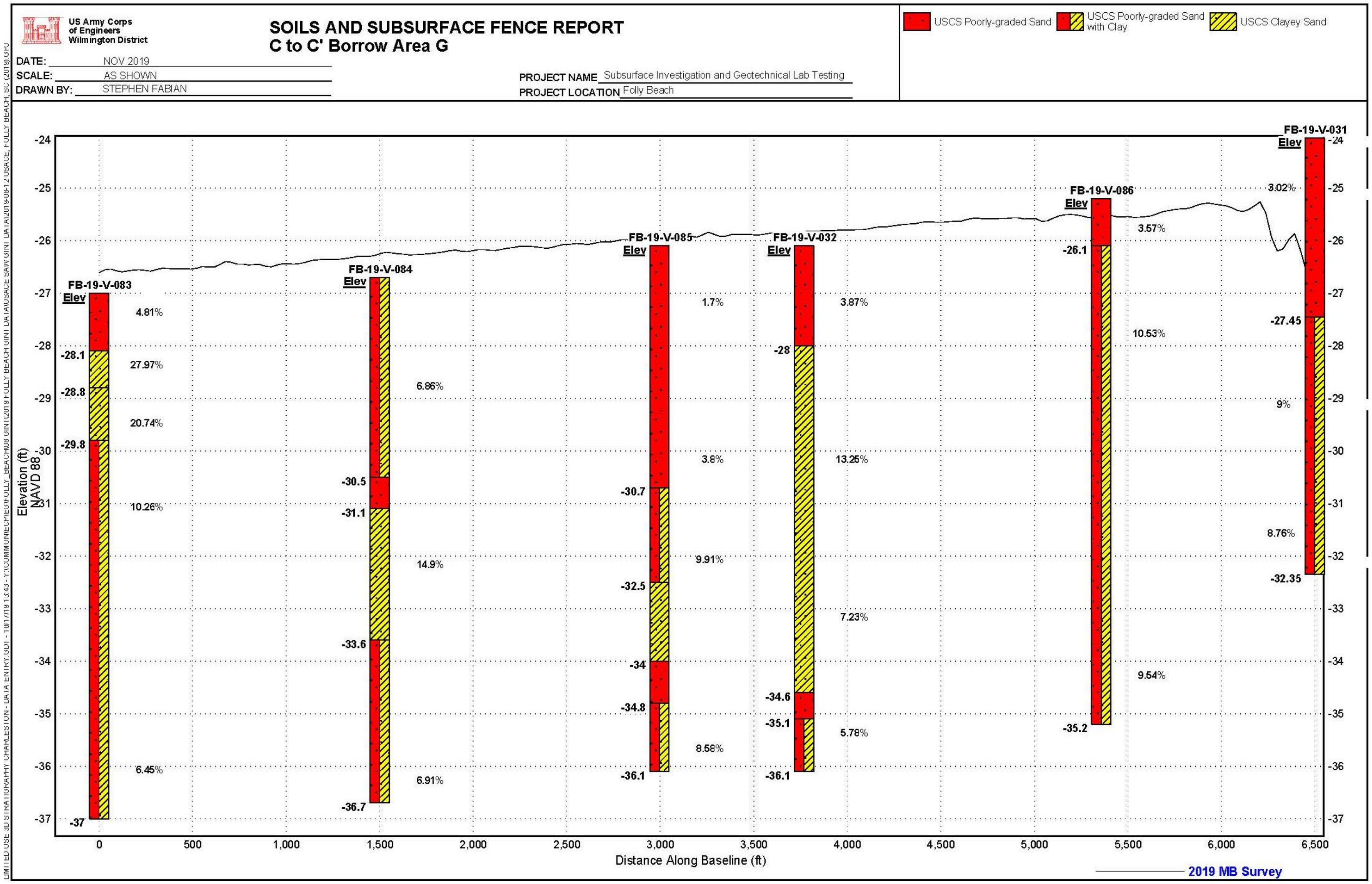

Figure 24. Fence diagram: C to C' borrow area G.

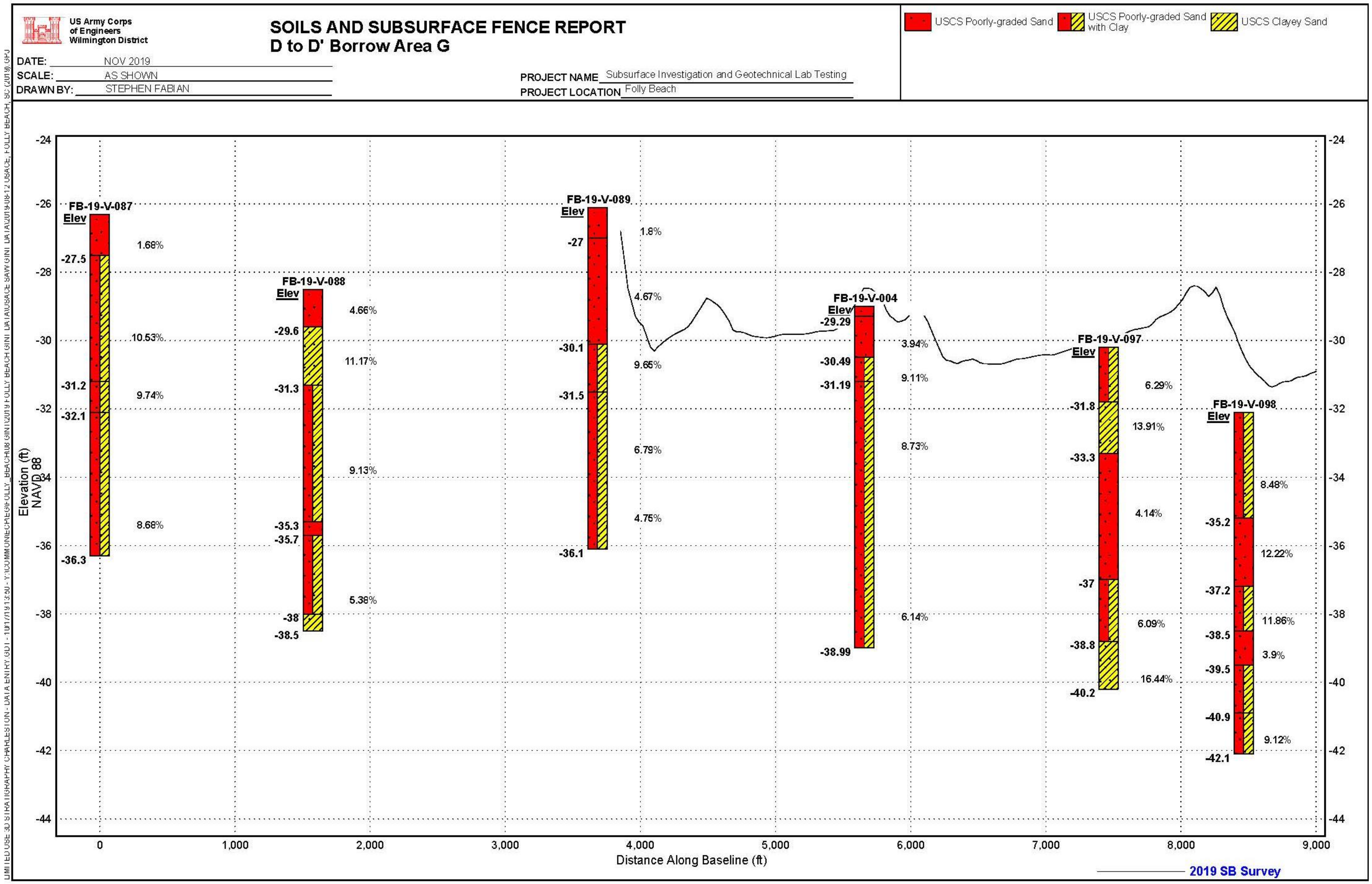

Figure 25. Fence diagram: D to D' borrow area G.

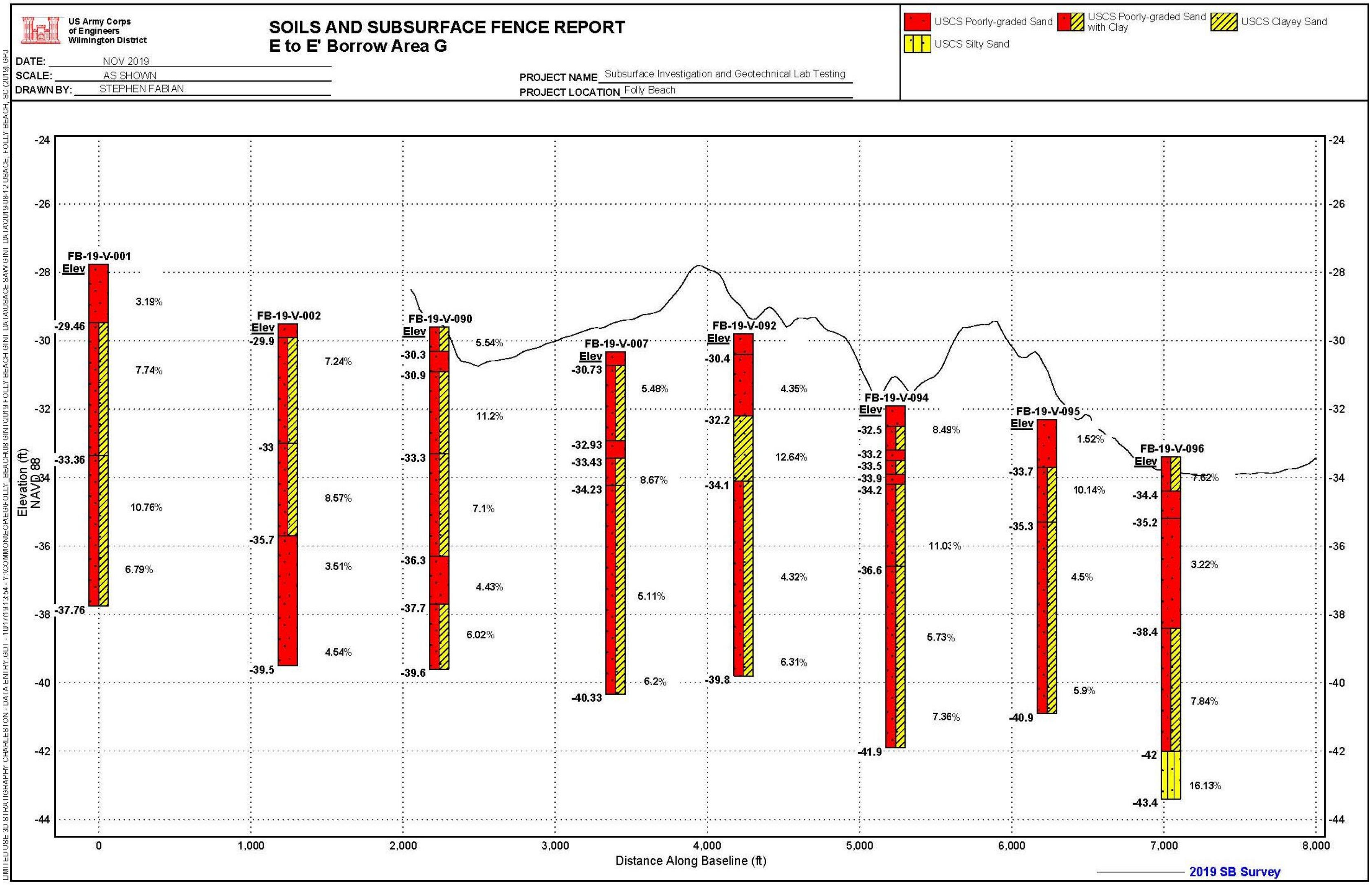

Figure 26. Fence diagram: E to E’ borrow area G.

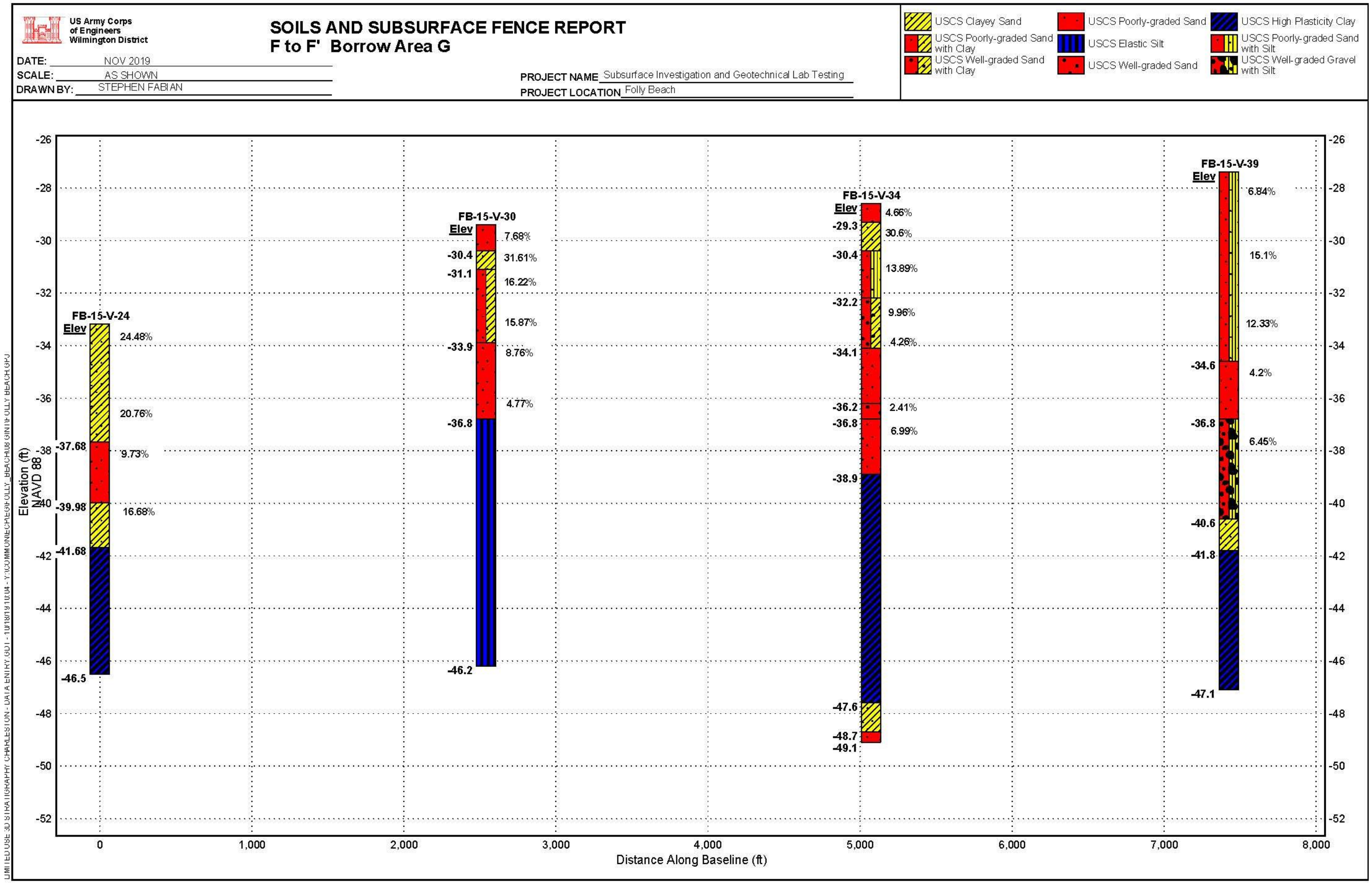

Figure 27. Fence diagram: F to F' borrow area G.

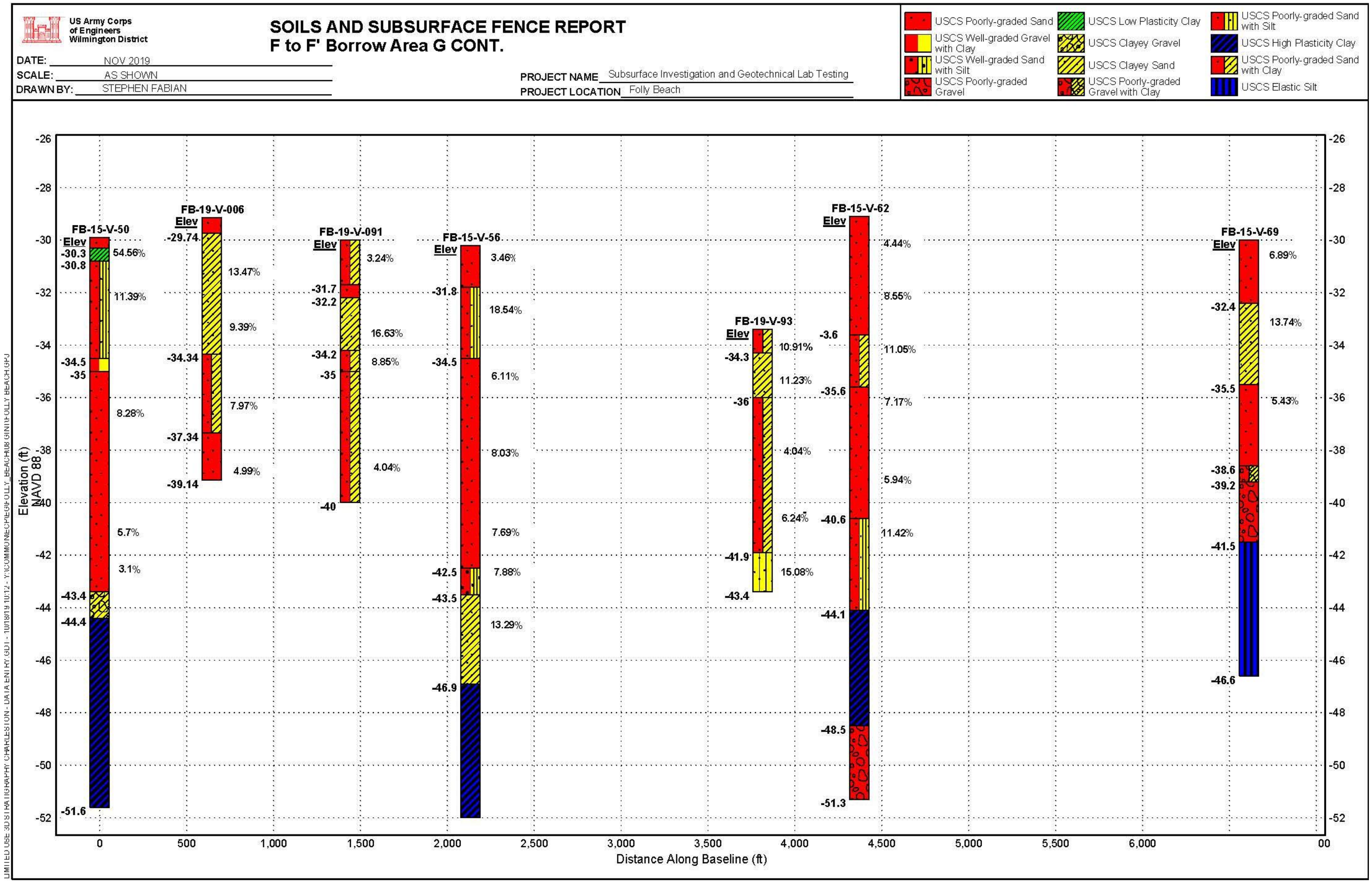

Figure 28. Fence diagram: F to F' Cont. borrow area G.

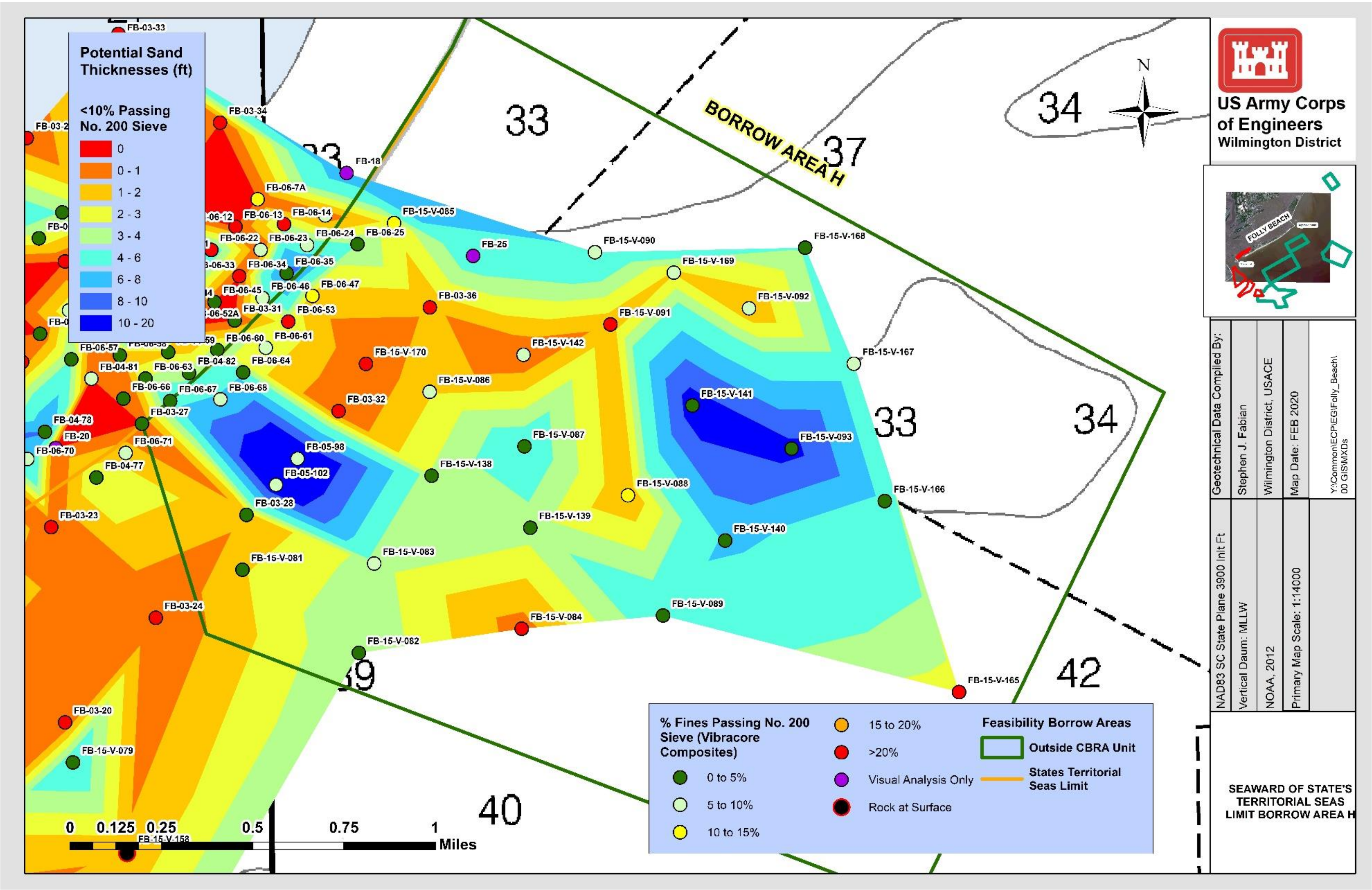

Figure 29. Usable sand thicknesses (ft) within borrow area H.

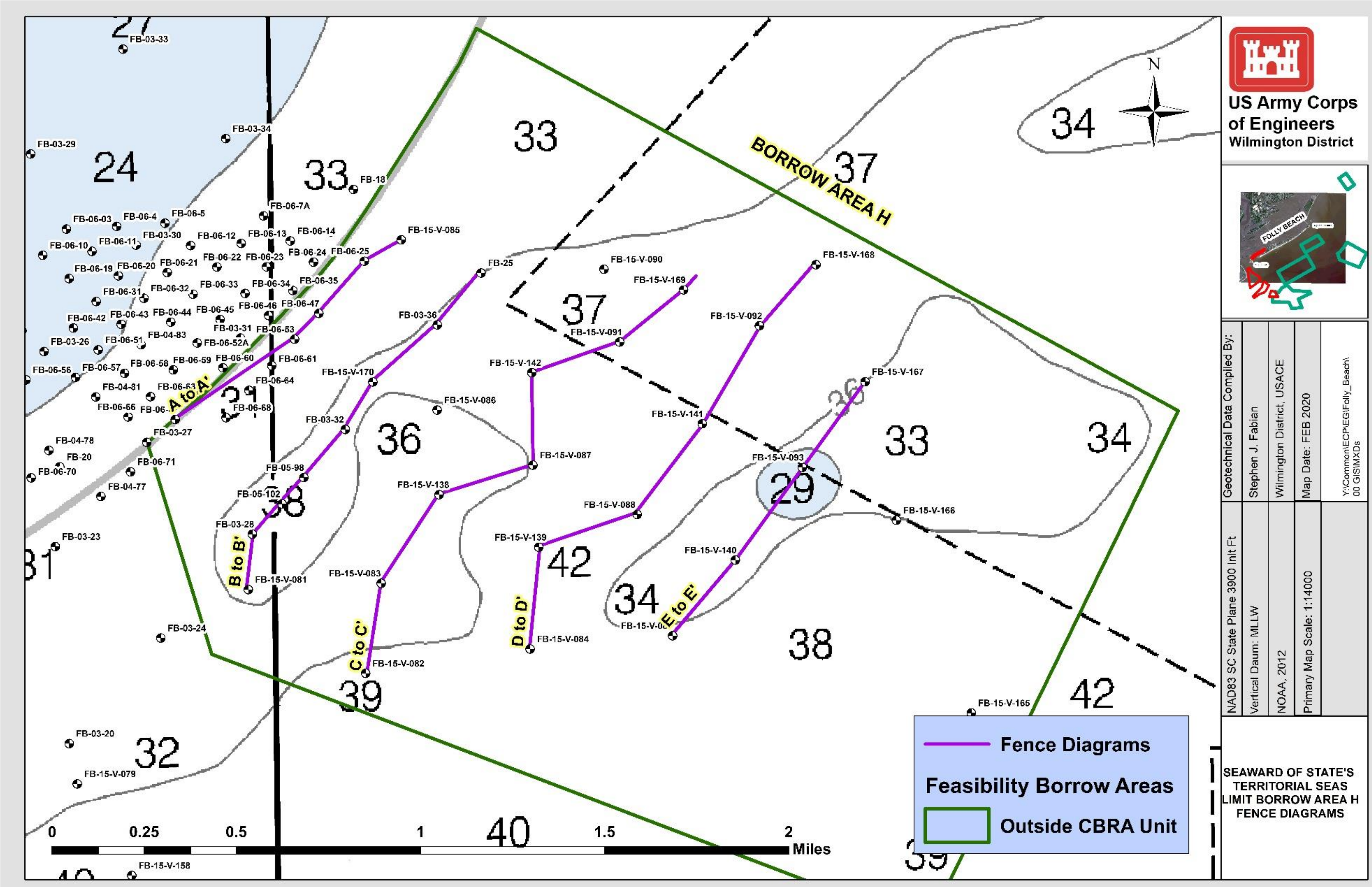

Figure 30. Borrow area H fence diagram locations.

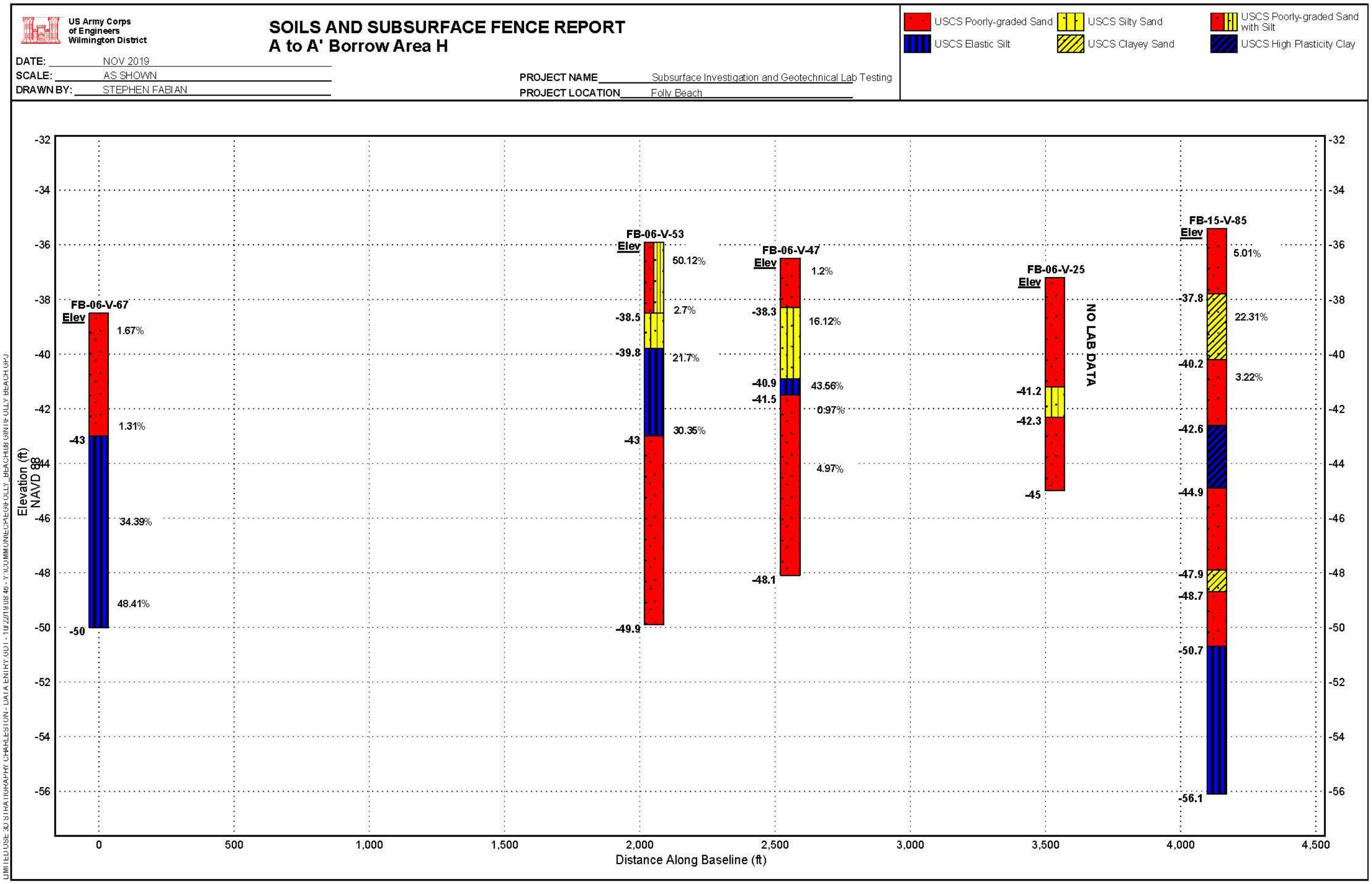

Figure 31. Fence diagram: A to A’ borrow area H.

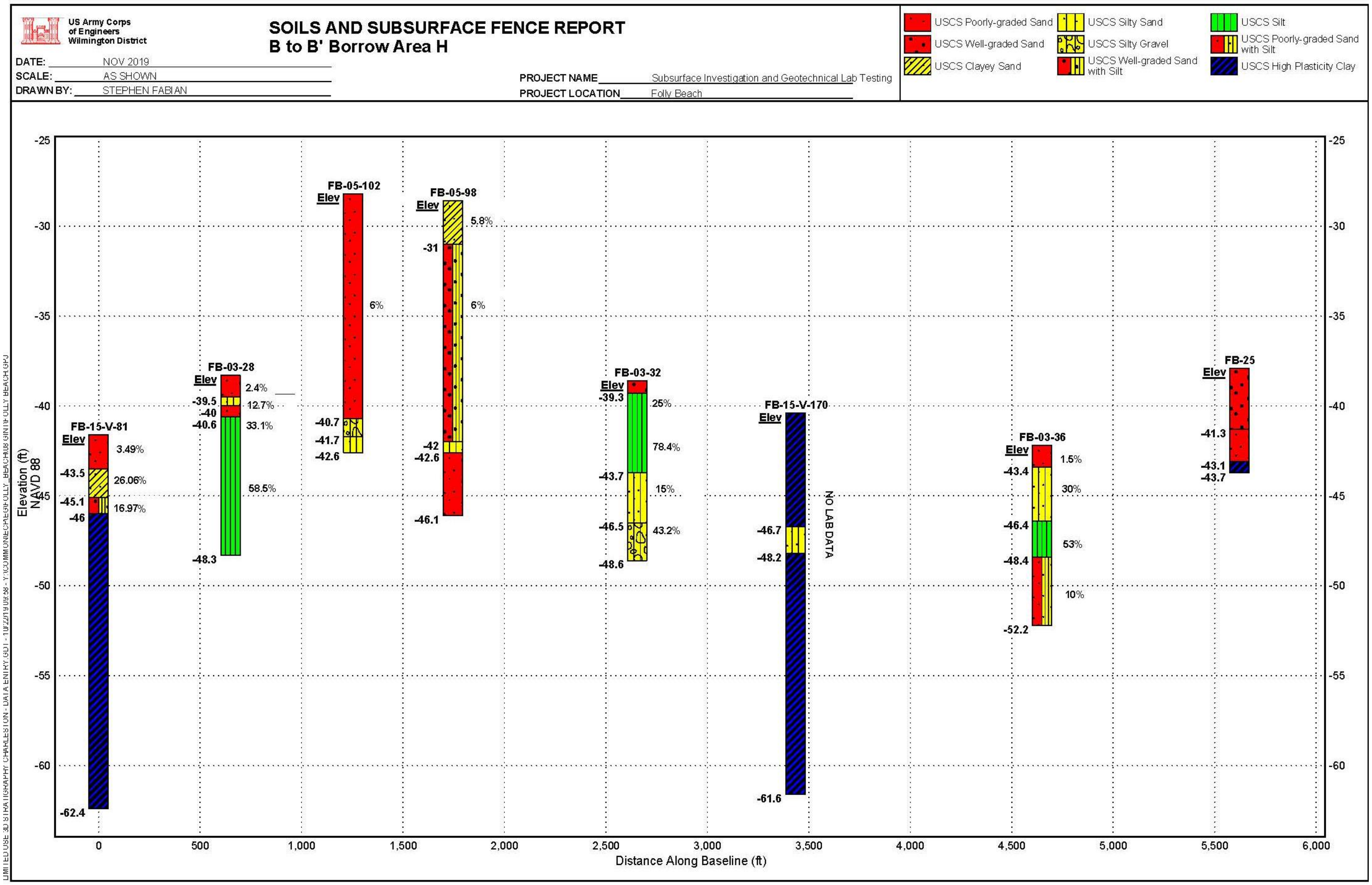

Figure 32. Fence diagram: B to B' borrow area H.

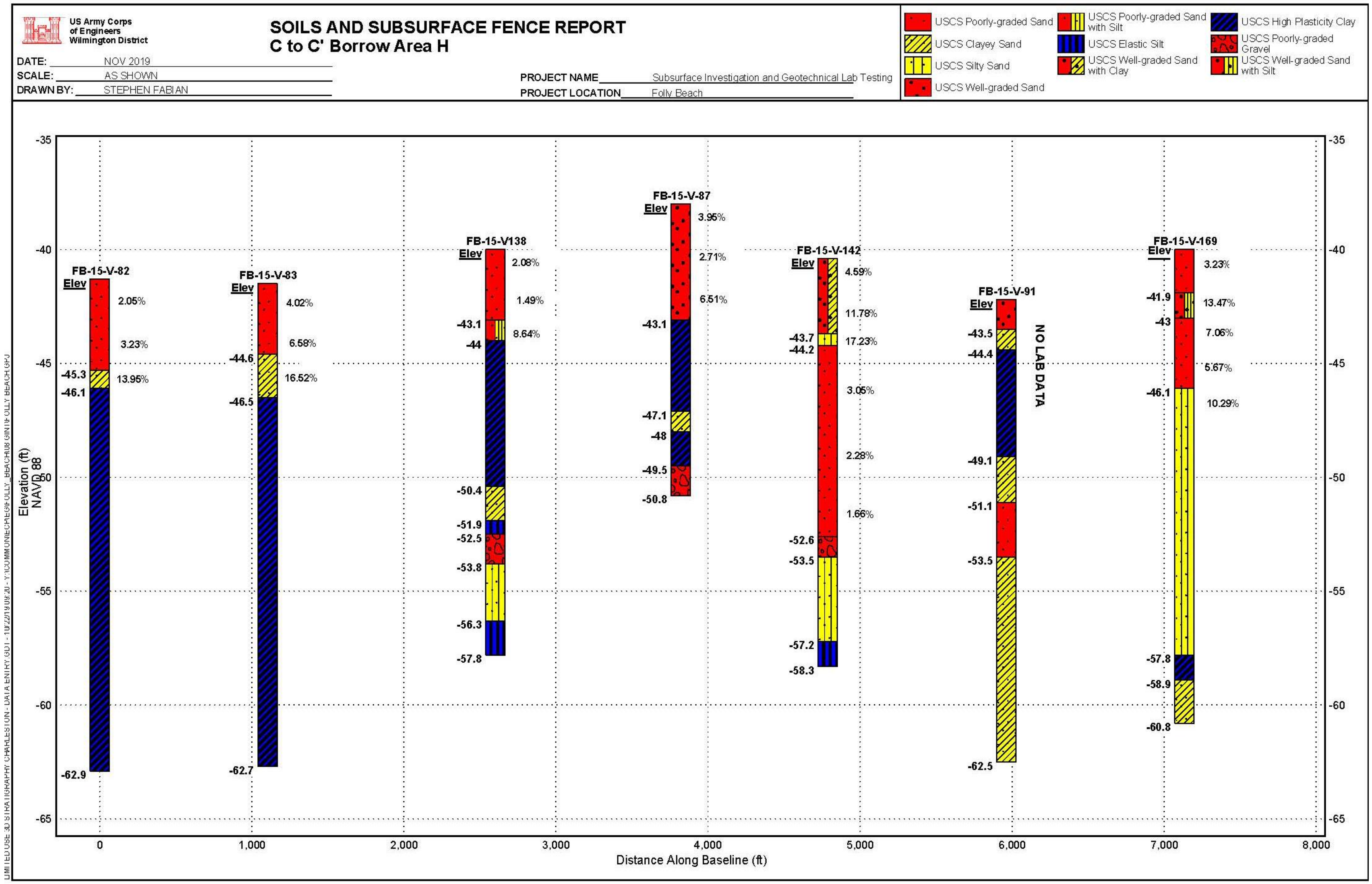

Figure 33. Fence diagram: C to C' borrow area H.

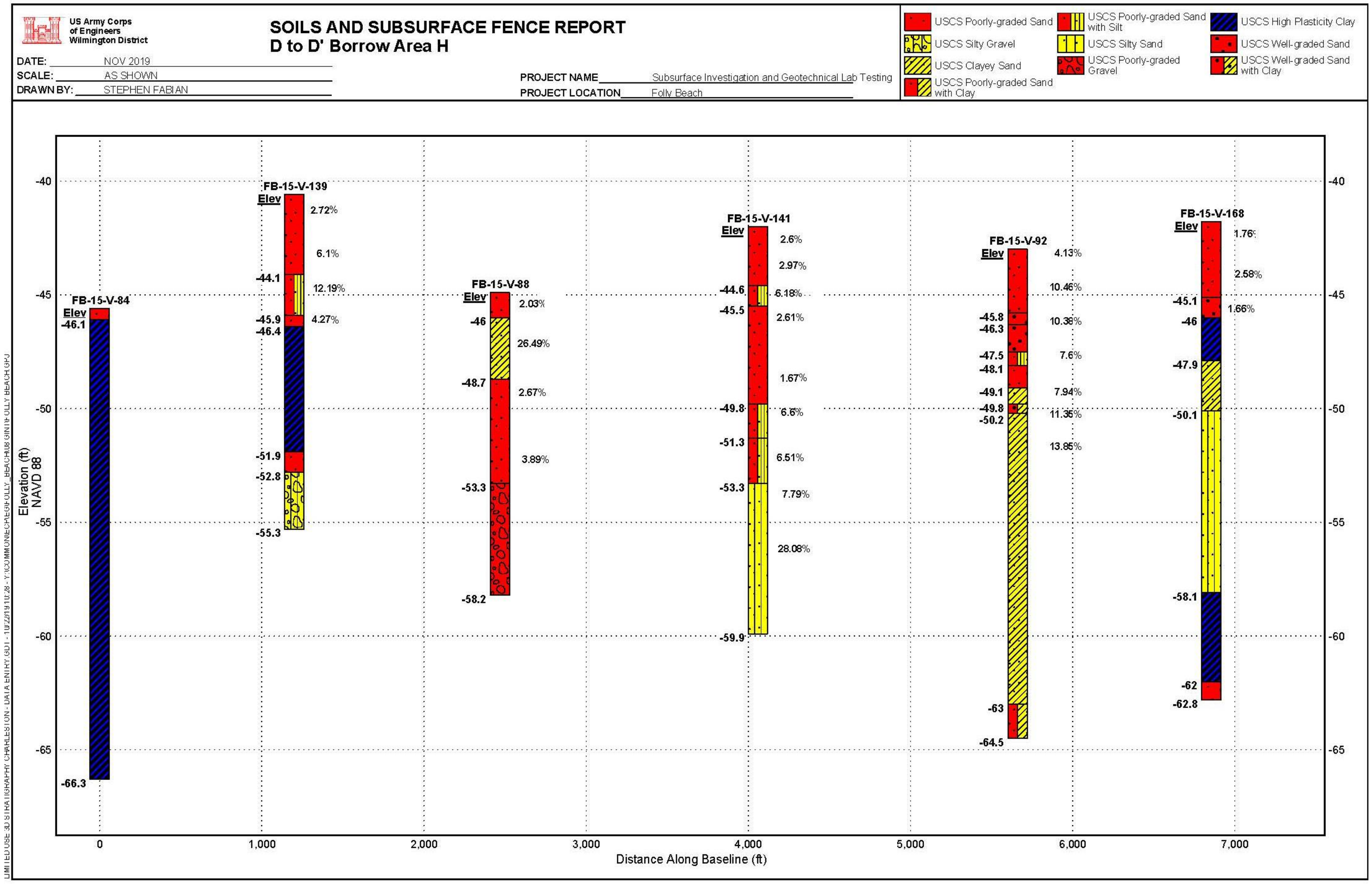

Figure 34. Fence diagram: D to D' borrow area H.

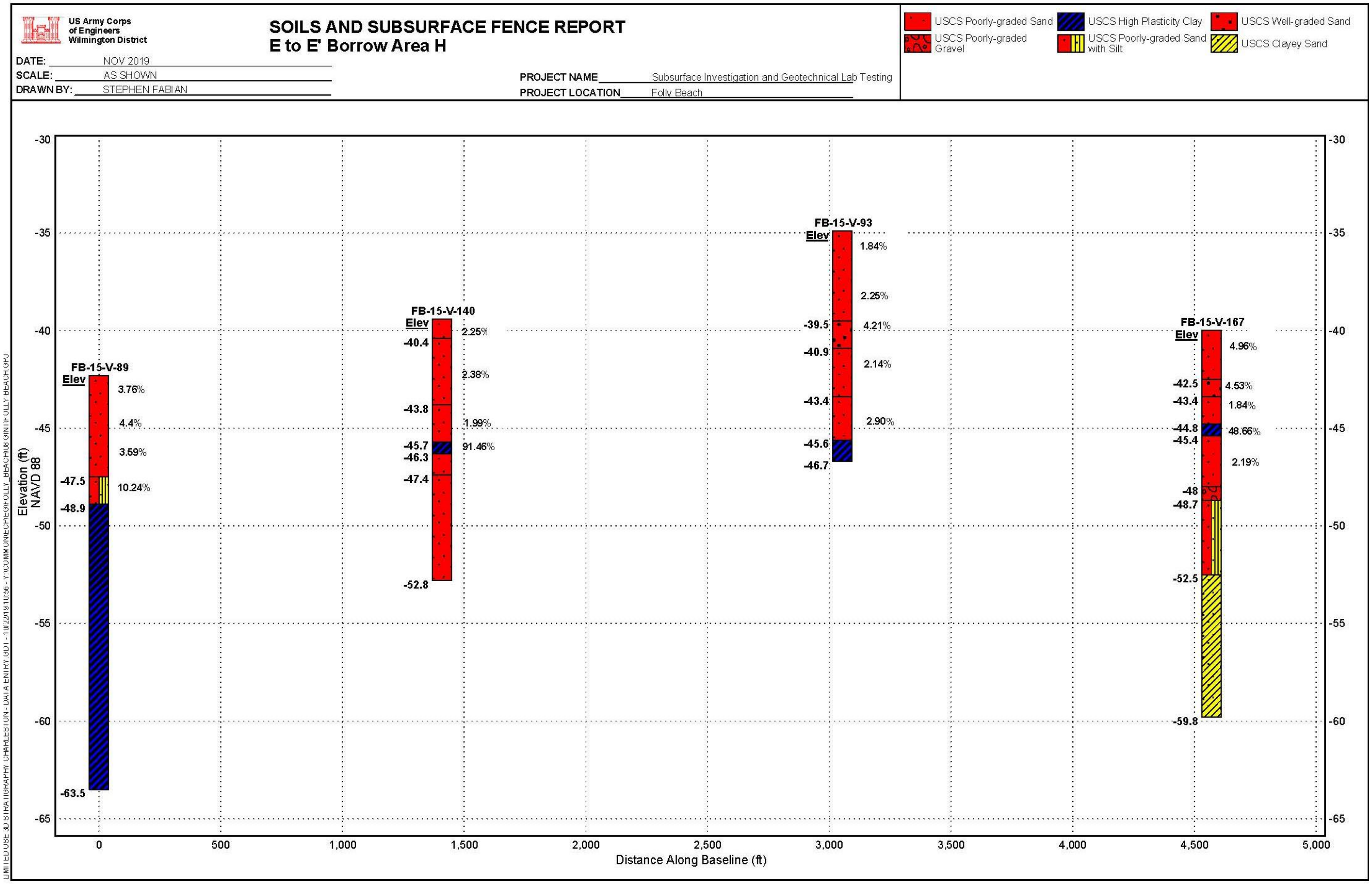

Figure 35. Fence diagram: E to E' borrow area H.

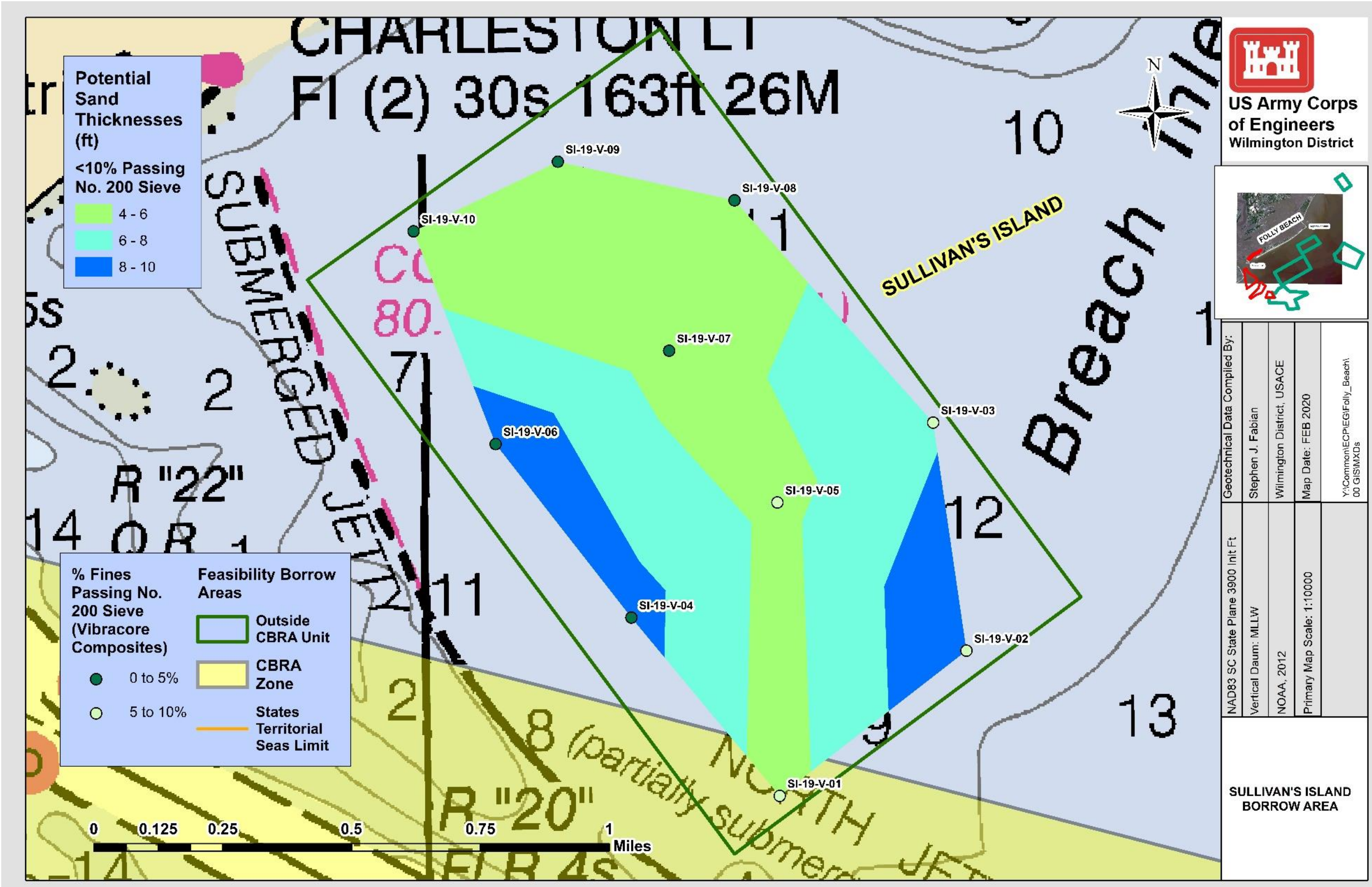

Figure 36. Usable sand thicknesses (ft) within the Sullivan's Island borrow source. The borrow source is the most northeastern polygon in the inset map. This borrow source is offshore Sullivan's Island which is updrift of the Charleston Harbor jetties.

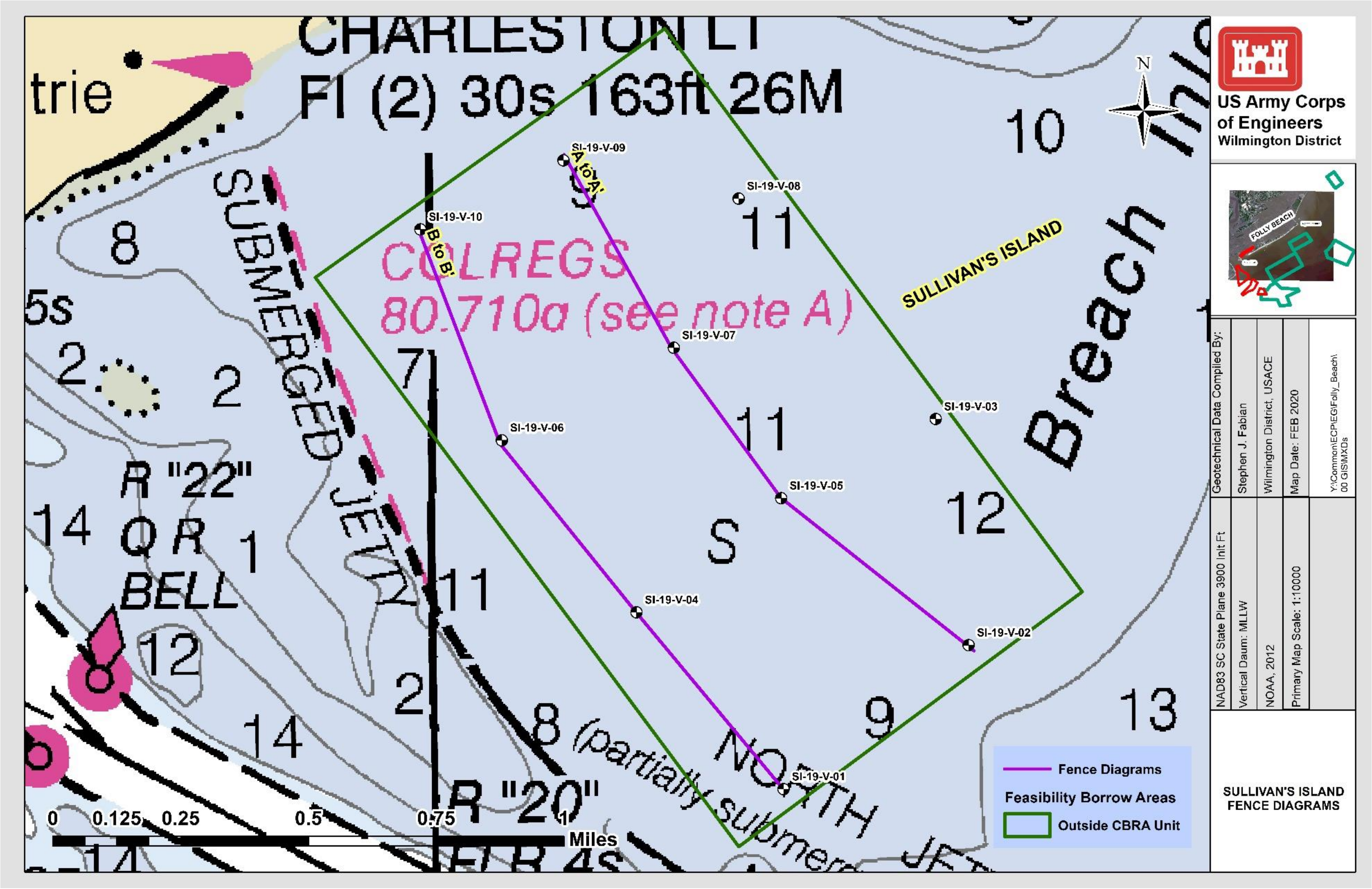

Figure 37. Sullivan's Island fence diagram locations.

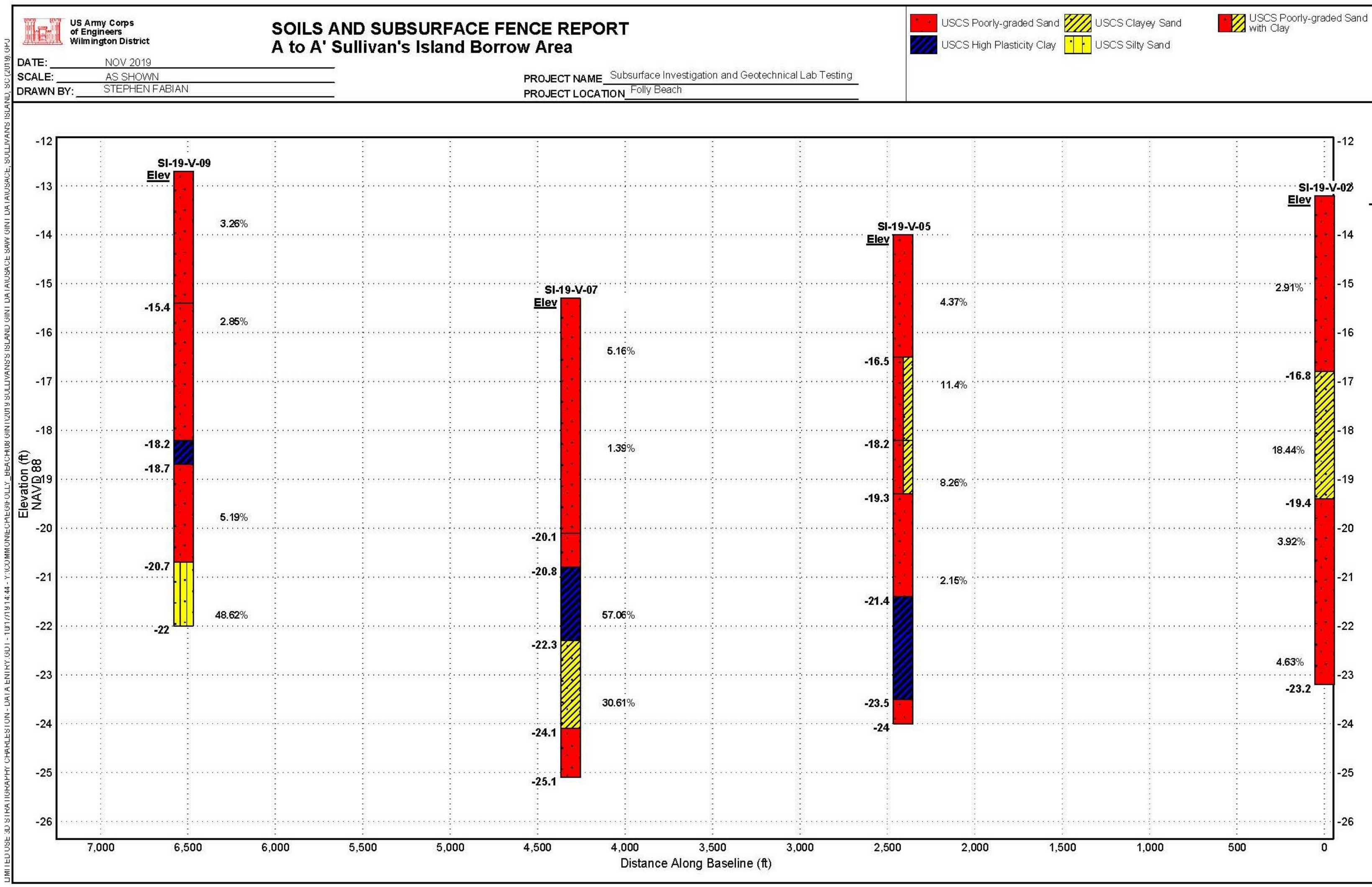

Figure 38. Fence diagram: A to A’ Sullivan’s Island.

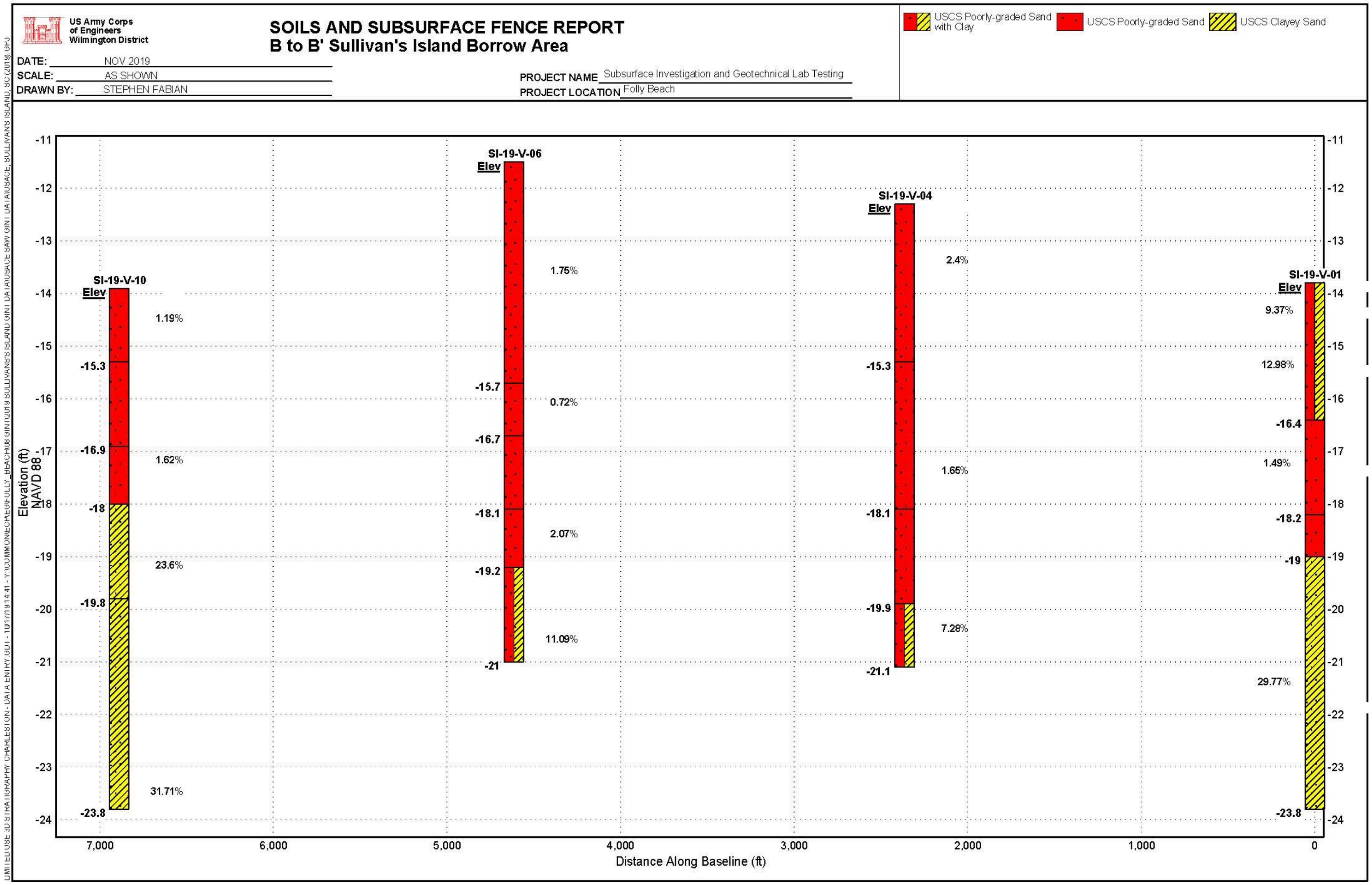

Figure 39. Fence diagram: B to B' Sullivan's Island.

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6.0 FEASIBLITY BORROW AREAS INSIDE CBRA ZONE

Borrow sources within CBRA zones are usually ideal for beach nourishment because of their proximity to the mouth of inlets which contain well-distributed, thick, and uniform, fine- to medium-grained sands within the flood and ebb shoals. Also, sources typically recharge from longshore sediment transport allowing the borrow source to be used more than once over a 50-year project life. Additionally, CBRA zone borrow sources that extend into the back-barrier (e.g. Folly River borrow area) provide significant protection from high wind and wave events making these areas more efficient in placing sand on the beach. This allows for dredging operations to be uninterrupted and limits the number of weather delays. Historically, USACE was prohibited from using federal funds to support beach nourishment which involved exploiting sand within CBRA zones. However, recent legal interpretations provided by United States Fish and Wildlife Service (USFWS) in 2019 will likely make CBRA zones available for federal projects.

The USFWS has specific guidelines that constrain the CBRA boundaries around barrier island complexes. Through the USFWS website a GIS shapefile[9] was obtained, providing the extents of the CBRA zone along the beachfront. However, the extents of the CBRA zone seaward are not accurately depicted in the shapefile. In the metadata of the shapefile the seaward boundary of CBRA extends to the -30 ft mean lower low water (MLLW) contour. This can drastically change usable sand volumes in and outside the CBRA zone. For this feasibility study, the boundaries of CBRA that extend seaward were dependent upon historical nautical charts and top of hole vibracore elevations from 2015. Vibracores within the CBRA extents, along the beachfront, but deeper than -30 ft MLLW, were considered outside the CBRA zone. A rough estimate of the -30 ft MLLW contour was created based on the described methods. To achieve better accuracy of the seaward extents of CBRA, a bathymetric survey would need to be performed to delineate the -30 ft MLLW contour.

Within the CBRA zone, four borrow areas were identified to be used for potential beach placement. Each of the four borrow areas are associated with the Stono Inlet complex. The closest borrow area is the Folly River (back-barrier flood channel) and the most distant ebb shoal (borrow area K) approximately 4 miles offshore. Figures 40 to 51 detail the usable sand thicknesses, percent fines, and show fence diagrams that depict the geologic framework of each borrow area.

6.1 FOLLY RIVER

The closest CBRA borrow area to Folly Beach is the Folly River borrow area (Figure 6). Historically, this source has been used for previous nourishments with the first use being initial construction in 1993. Thereafter, the Folly River has been used for periodic nourishments with the most recent use in 2018 placing 500,000 yd^3 of sand on Folly Beach. Vibracore data from 2012 and 2015 show usable sand thicknesses reach up to 20.0 ft and averaging 14.0 ft. The water depths range from -4 to -15 ft. Grain sizes in this borrow area range from 0.14 mm to 0.21 mm (2.84 phi to 2.25 phi) with an average grain size of 0.16 mm (2.64 phi). Percent of fines passing the No. 200 sieve averages 2.20% (Figure 40).

[9] https://www.fws.gov/cbra/maps/Boundaries.html

The Folly River is mostly comprised of poorly graded sands with intermittent layers of clayey and silty sand lenses (< 0.3 ft). Underlying the poorly graded sand layer is a 1.0 to 2.0 ft layer of clayey sand. The bottom most layer is a high plasticity clay, which begins at -22 ft and varies in depth across the borrow area (Figures 41 to 43).

Since the completion of jetty construction in 2014, the recharge rates into the Folly River have decreased. According to previous engineering reports, the Folly River had a recharge rate of 18.0% per year before the completion of the jetty. Translating to any material removed and used for nourishment would require a waiting period of approximately five years until the area could be used again nourishment. Post jetty construction hydrographic surveys from 2014 to 2019 indicated a recharge rate average of 12.5% per year, which extends the waiting period from five years to eight years before it could be utilized for nourishment.

The most recent dredging event in the Folly River occurred in 2018. Therefore, to use the Folly River before it fully recharges, modifications to the borrow area footprint and allowable dredge depth would need to be approved. However, modifying the footprint and deepening the Folly River could alter hydrodynamic exchange within the Stono Inlet complex. This was seen in the Folly River during initial construction in 1993. Severe erosion was documented on the southwestern end of Folly Beach. Nearly 3,000,000 yd^3 were pulled out of the Folly River resulting in significant changes to the flood and ebb tidal currents. If the Folly River were to be dredged and used for initial construction or periodic nourishments over the life of the project, a sophisticated borrow area impact analysis would need to be performed.

6.2 BORROW AREA I

Borrow area I is located within Stono Inlet (Figure 6). Water depths range from 0 to -36 ft based on vibracore data from 2015. Usable sand thicknesses reach up to 14.0 ft and average 9.7 ft. Grain sizes in this borrow area range from 0.11 to 0.25 mm (3.18 phi to 2.00 phi) and average 0.17 mm (2.56 phi). Percent of fines passing the No. 200 sieve averages 2.2% (Figure 44).

Borrow area I consists of poorly graded fine sand with intermittent layers of clayey and silty sand lenses (< 0.3 ft; Figures 45 to 47). Vibracore locations were taken alongside the main ebb channel to capture the suitable sands before encountering clayey sands and fat clays. The clayey sands exist at -22 ft and fat clays are encountered at -33 ft. Some of the vibracores collected were only described visually while others were sampled for lab analysis using the composite and sampling method, that resulted in several feet of core with no noticeable layers of unsuitable material. If this area is used for nourishment, additional cores and tighter sampling would need to be conducted to better classify borrow area I's material. Another caveat is that a large portion of this borrow area has never been used for nourishment and a possible drawback is its closeness to critical habitat for nesting shorebirds. Removal of shoaled material within Stono Inlet could have negative effects on nearby shorebird nesting islands (e.g. Bird Key Island) resulting in potential erosion and displacement of this critical habitat. A sophisticated borrow area impact analysis would need to be performed to determine the short-and long-term effects of dredging on the hydrodynamic changes to Stono Inlet.

6.3 BORROW AREAS J AND K

Borrow areas J and K are associated with Stono Inlet's large ebb-tide delta (Figure 6). Water depths range from -4 to -30 ft based on vibracore data from 2015. Usable sand thicknesses reach up to 13.8 ft and average 6.8 ft. The grain sizes range from 0.11 to 0.26 mm (3.18 phi to 1.94 phi) and average 0.18 mm (2.47 phi). Percent of fines passing the No. 200 sieve averages 5.3% (Figure 48).

In between the two borrow sources lies an area of unsuitable material containing clayey sands, silts, and fat clays. Borrow area J has a thick area of usable sand until it encounters a well-defined unsuitable continuous fat clay and clayey sand at -27 ft. Borrow area K also has a thick area of usable sand and encounters a well-defined unsuitable continuous fat clay and clayey sand at -43 ft (Figures 49 to 51).

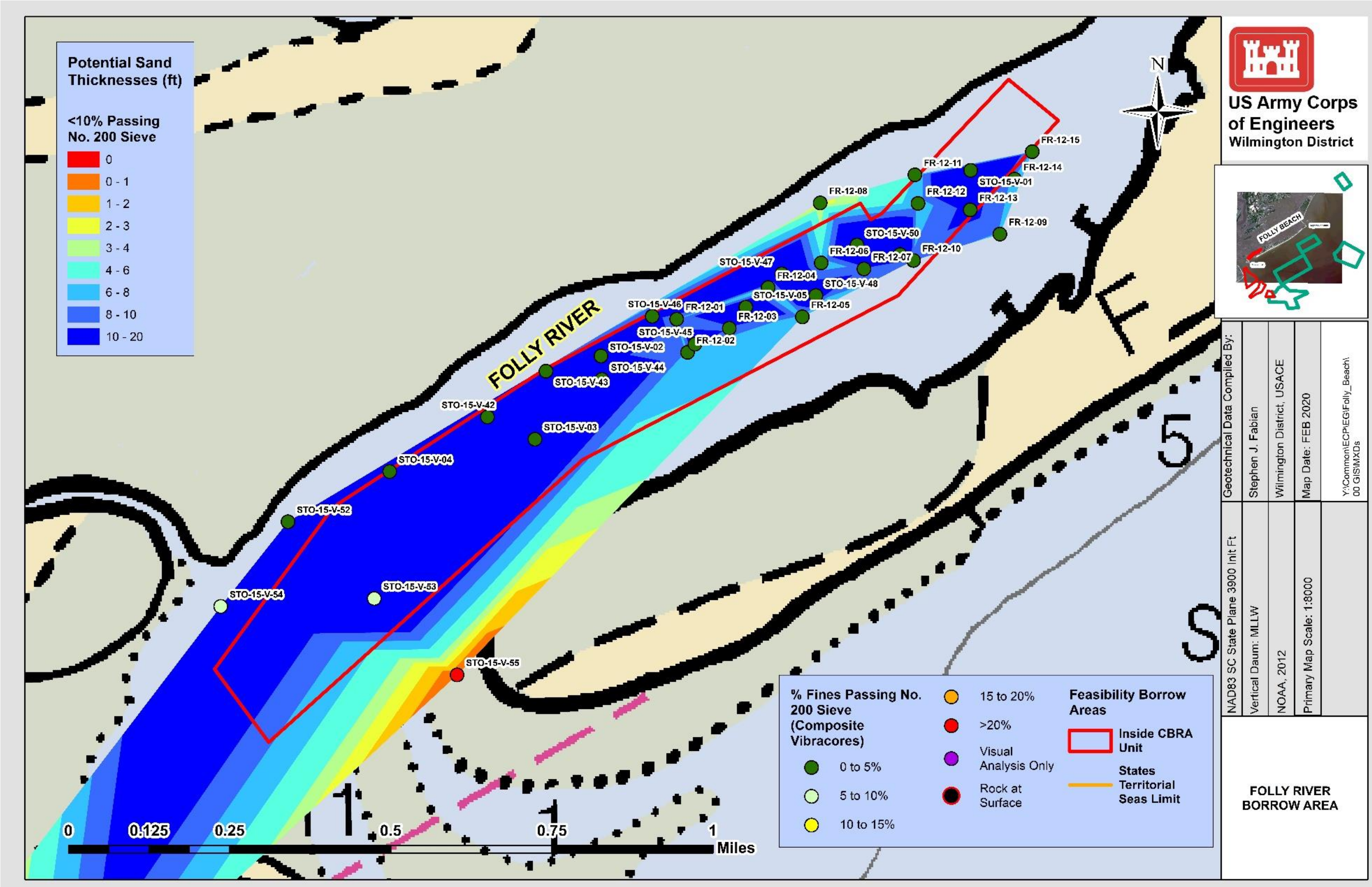

Figure 40. Usable sand thicknesses (ft) within Folly River borrow source.

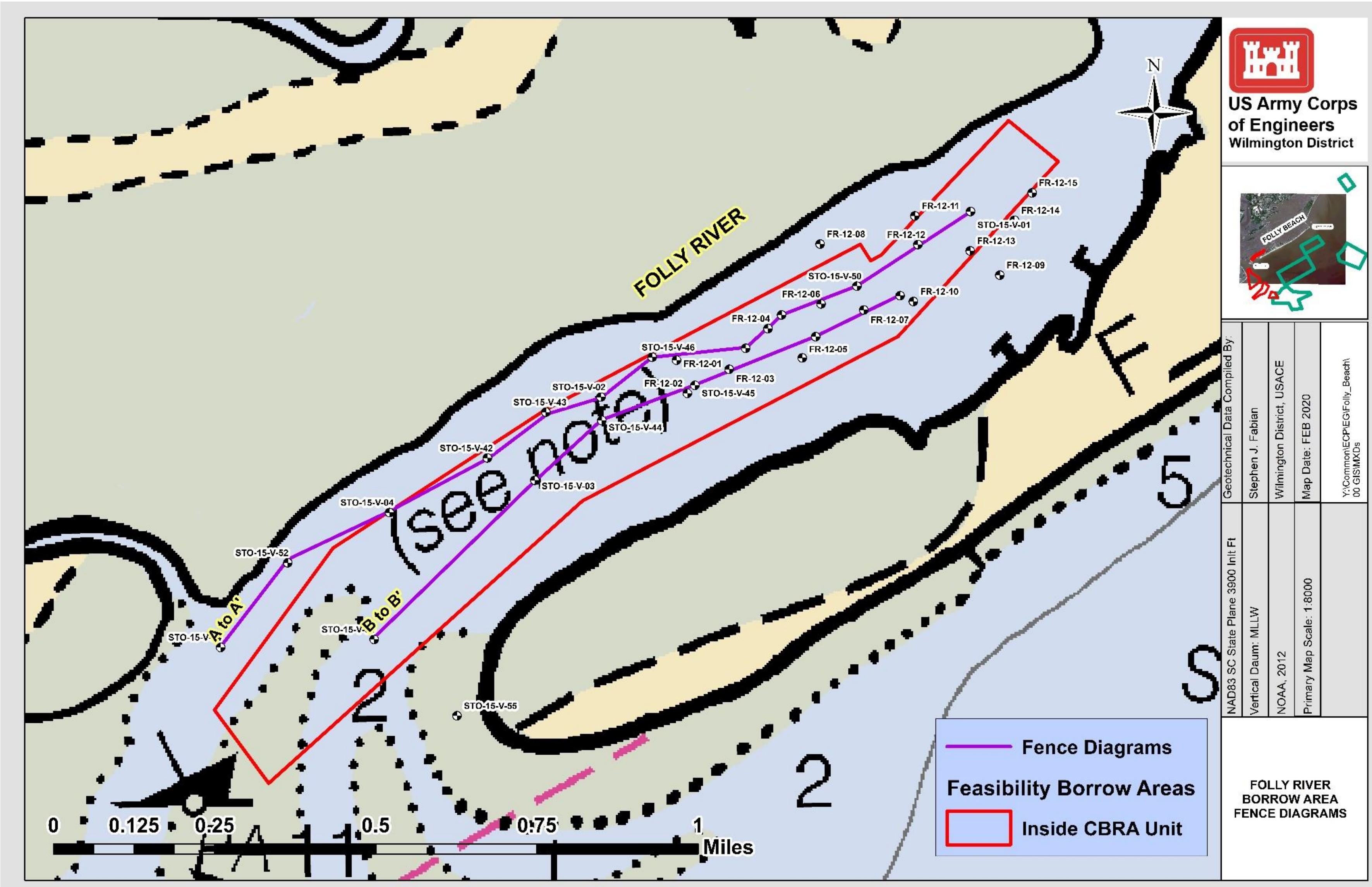

Figure 41. Folly River fence diagram locations.

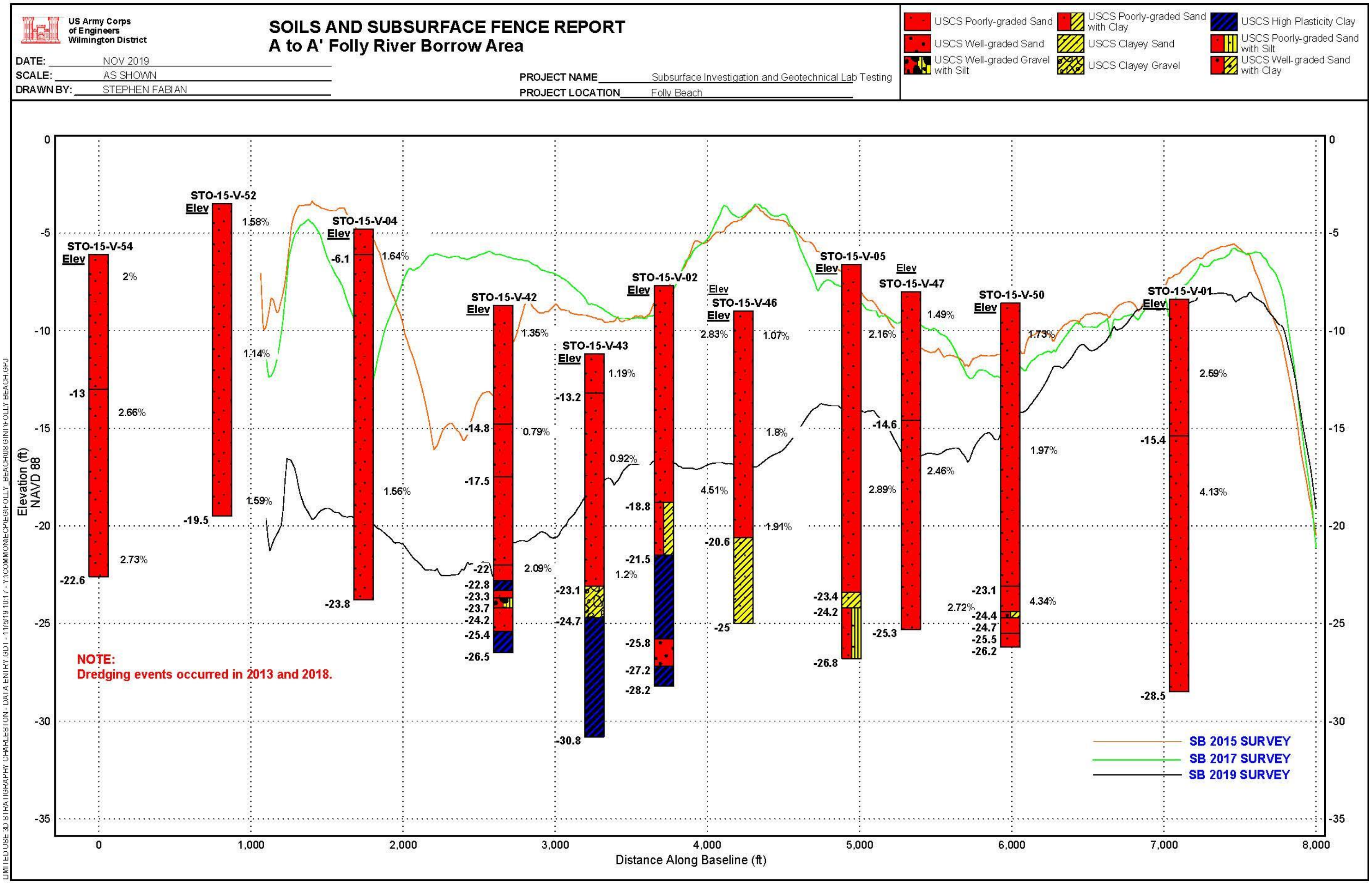

Figure 42. Fence diagram: A to A' Folly River borrow area.

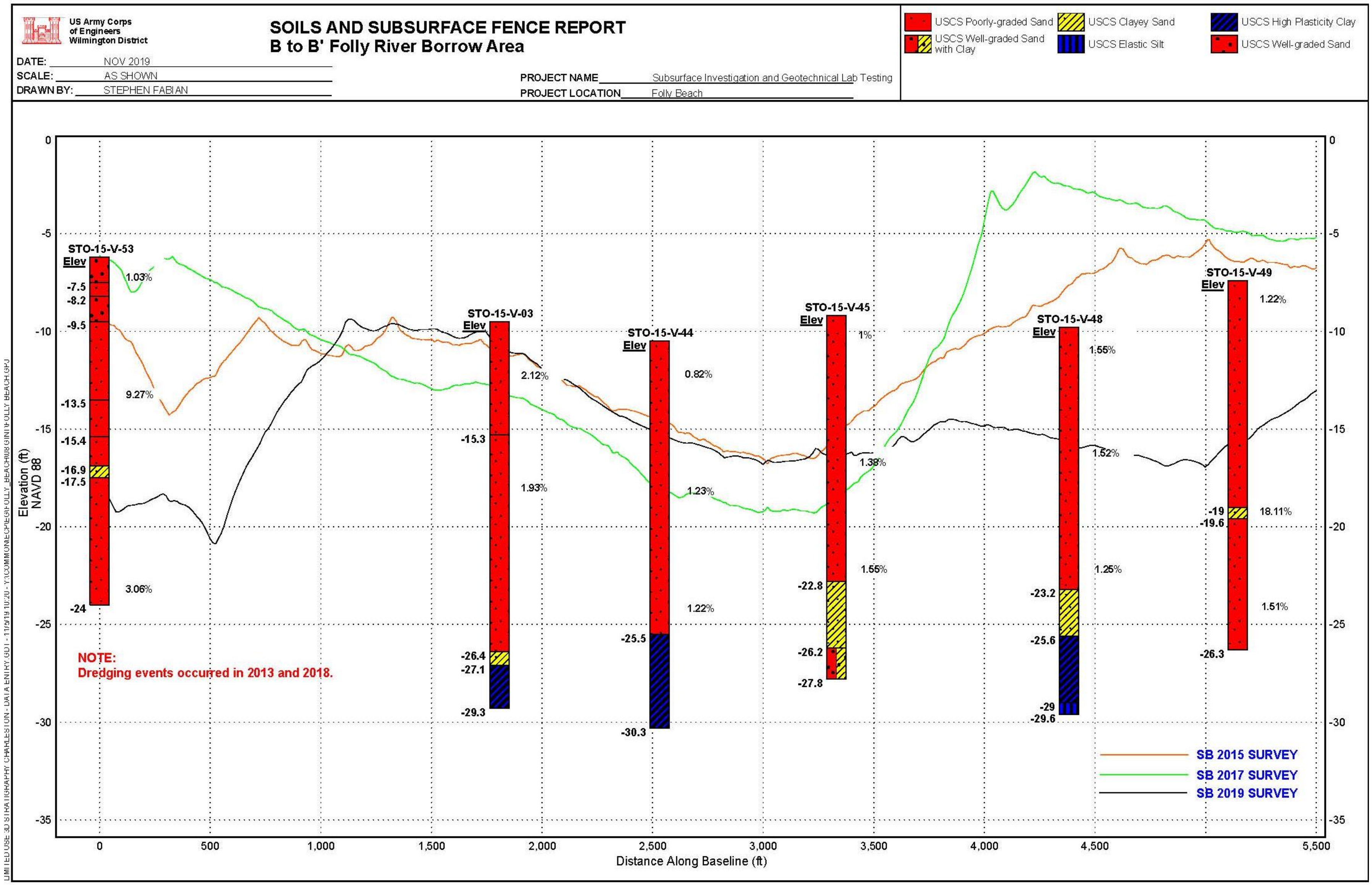

Figure 43. Fence diagram: B to B' Folly River borrow area.

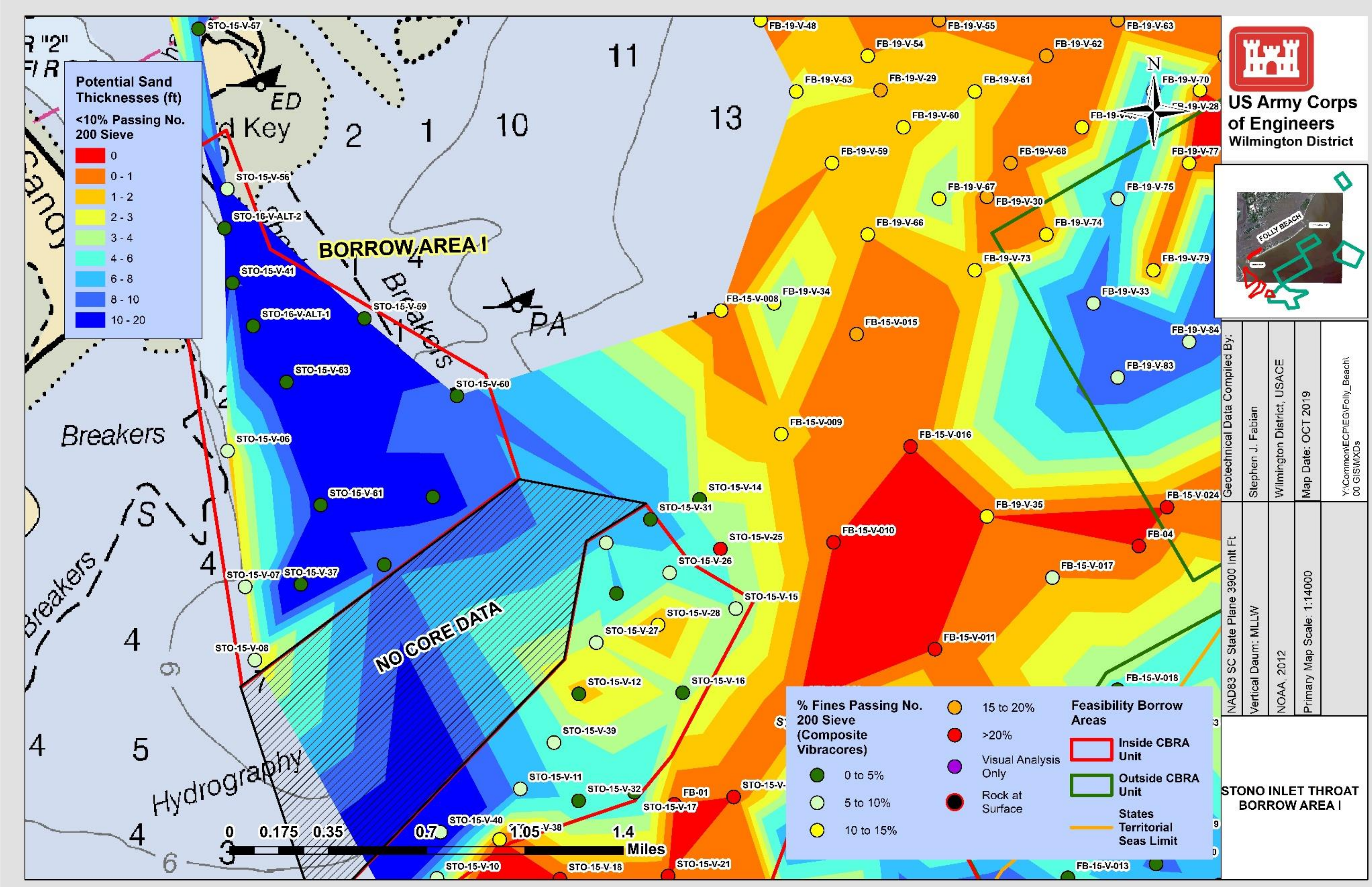

Figure 44. Usable sand thicknesses (ft) within borrow area I.

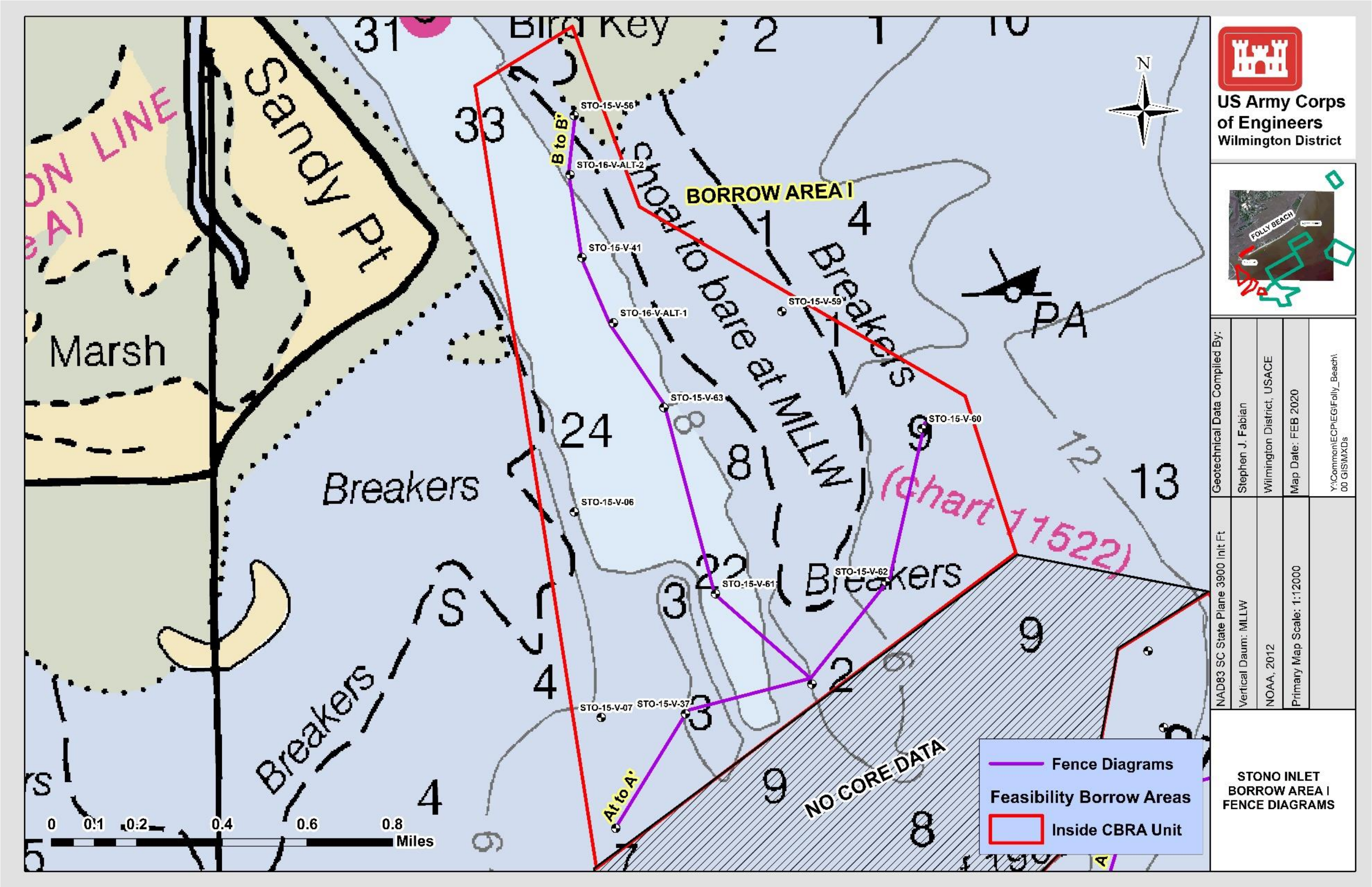

Figure 45. Borrow area I fence diagram locations.

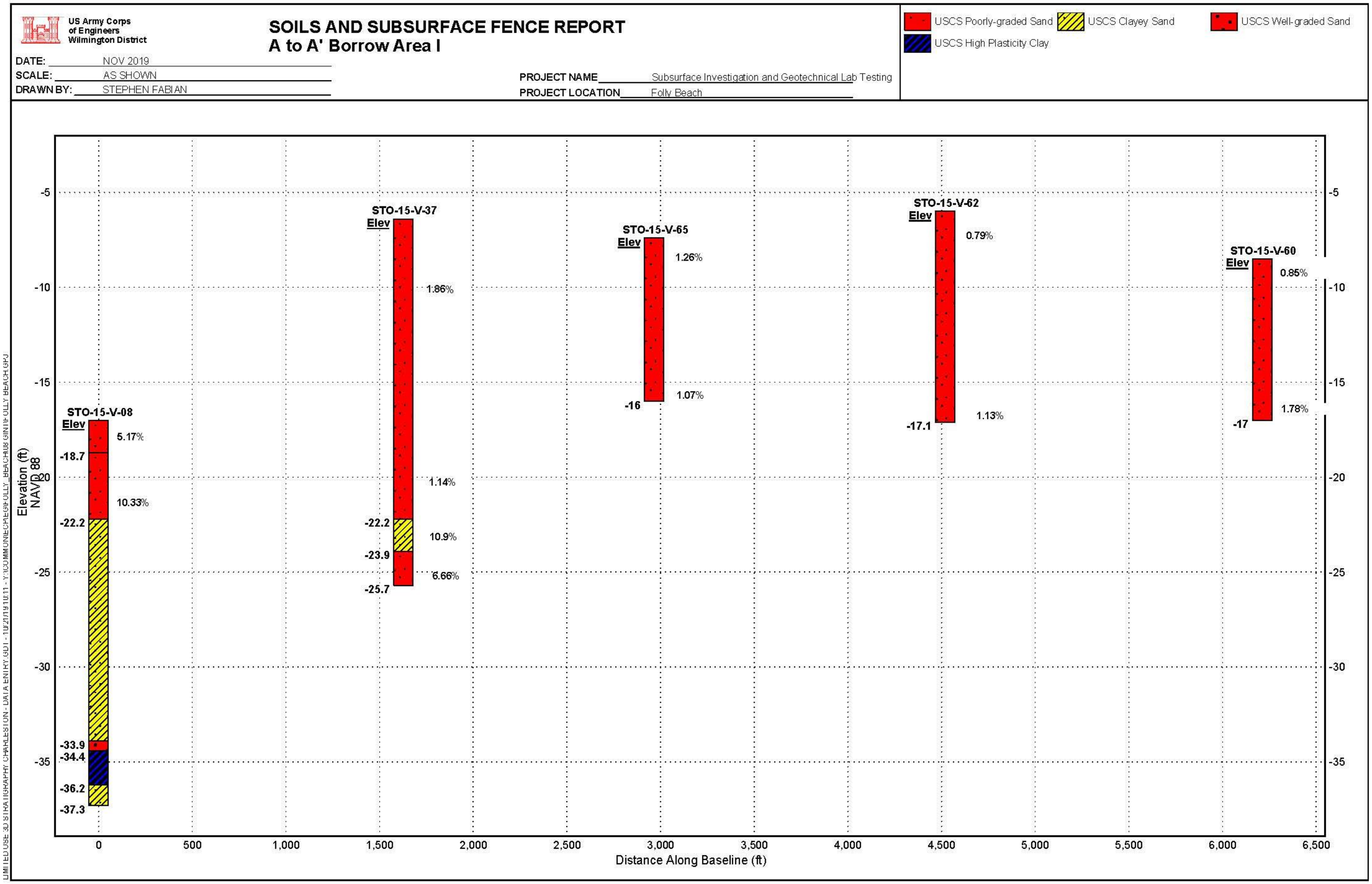

Figure 46. Fence diagram: A to A' borrow area I.

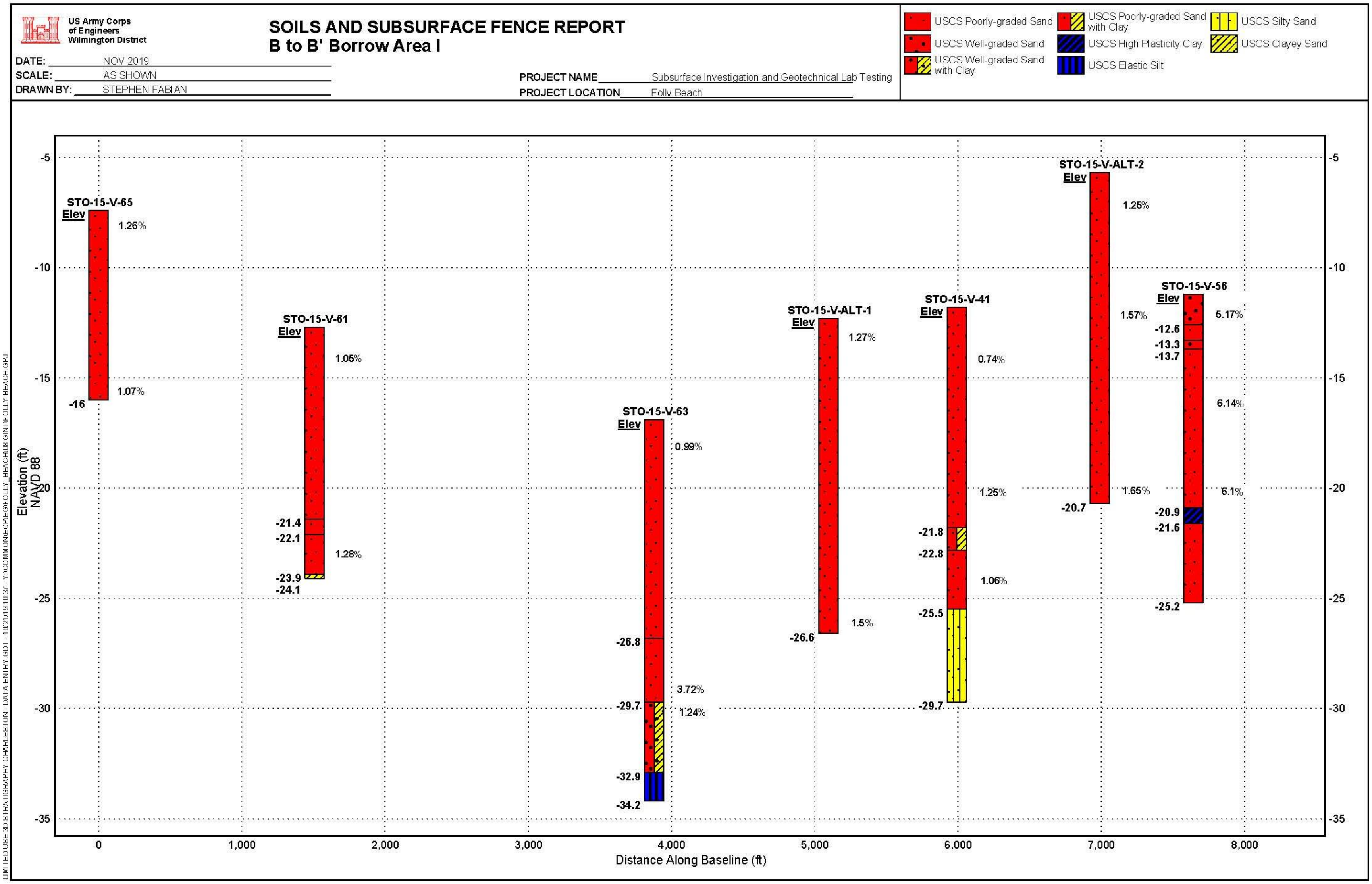

Figure 47. Fence diagram: B to B' borrow area I.

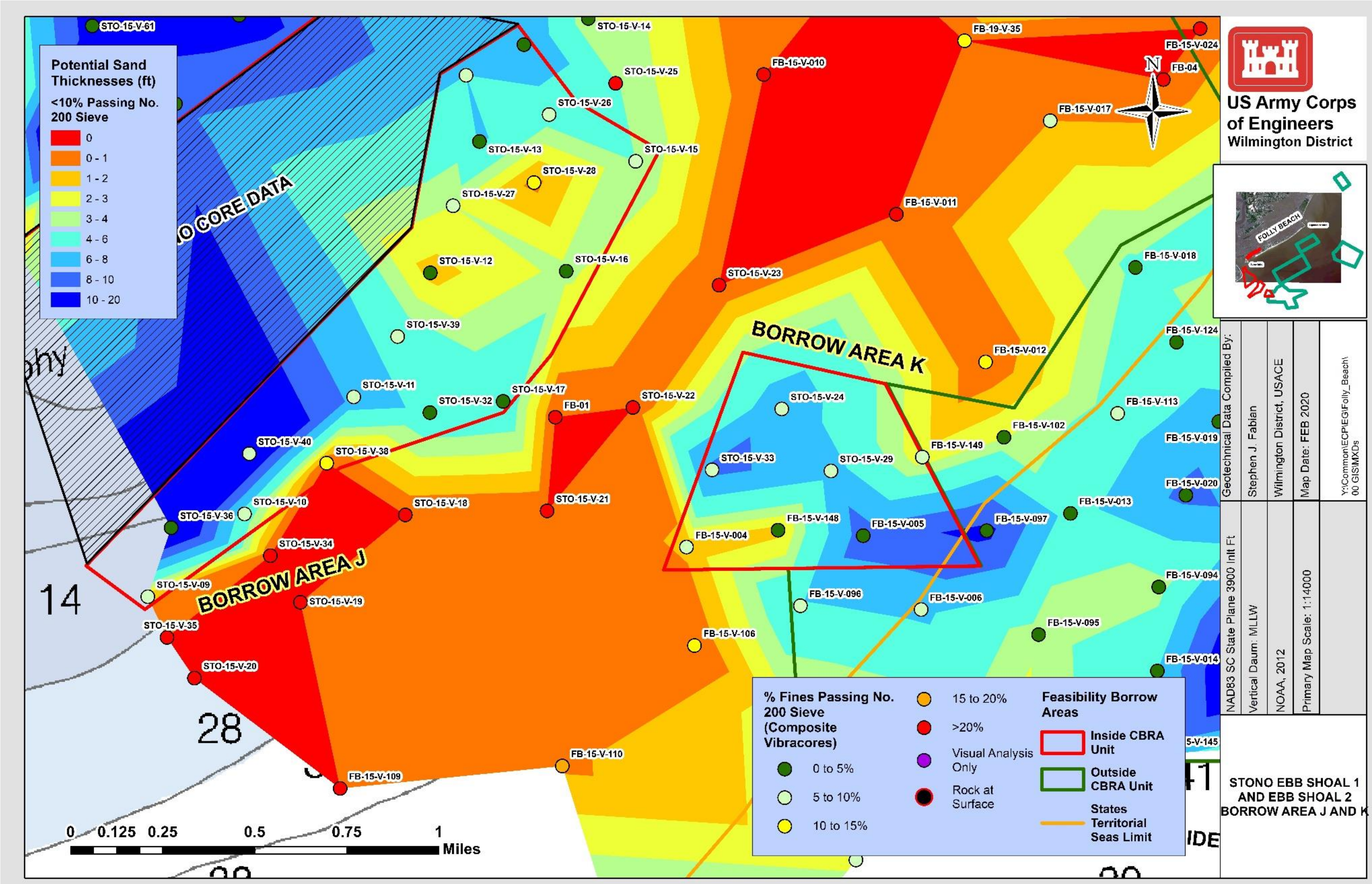

Figure 48. Usable sand thicknesses (ft) within borrow areas J and K.

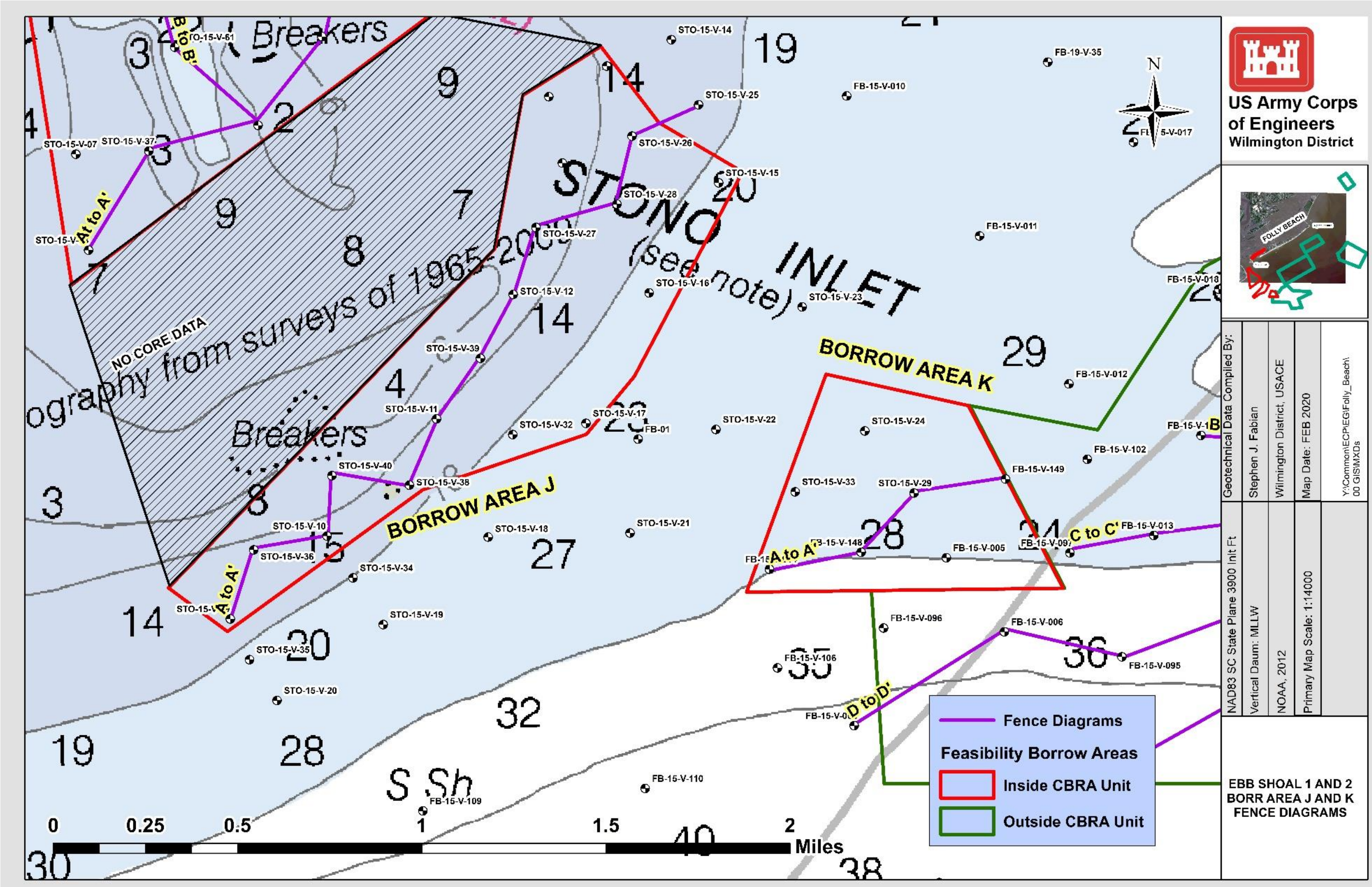

Figure 49. Borrow area J and K fence diagram locations.

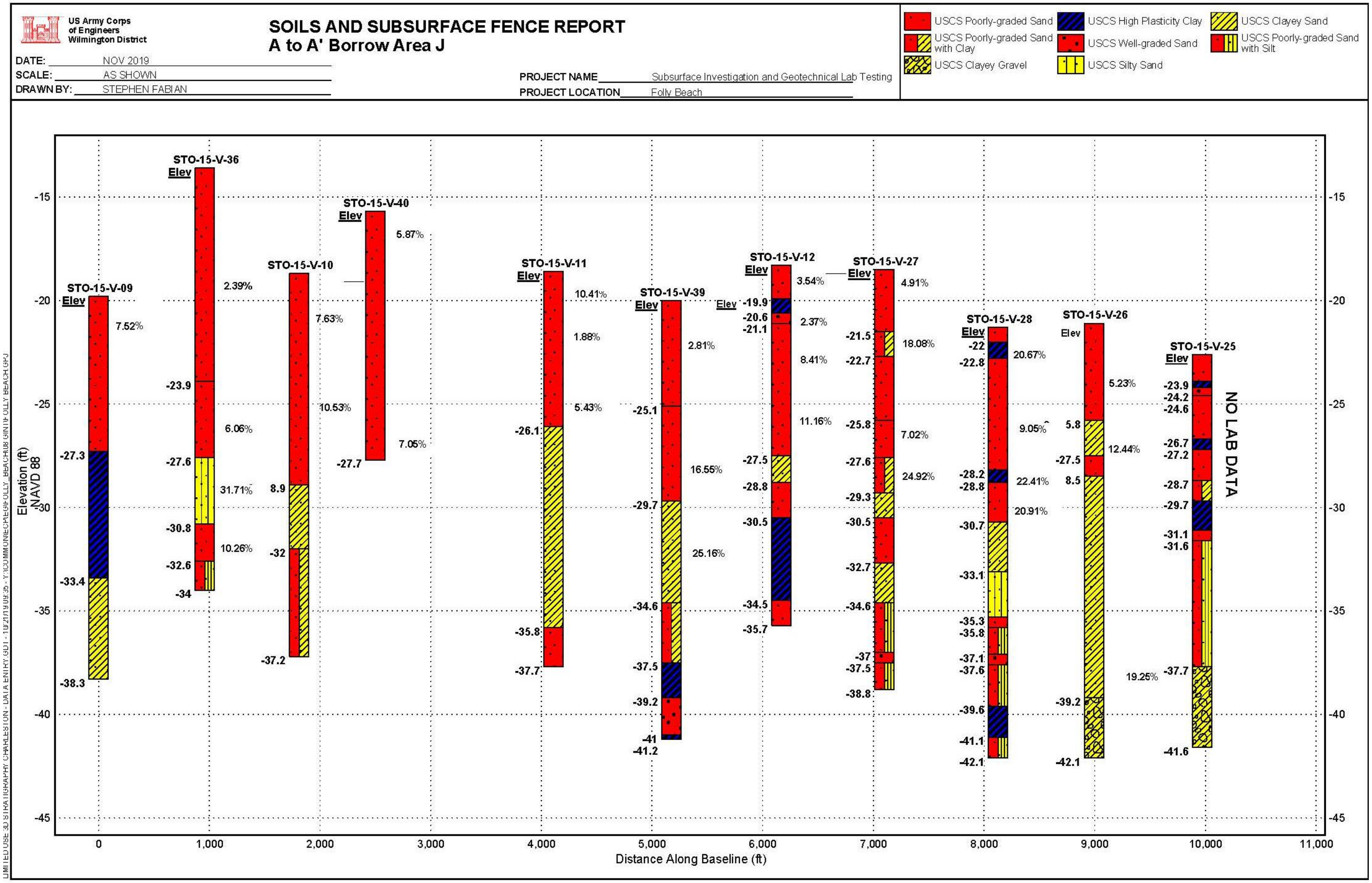

Figure 50. Fence diagram: A to A' borrow area J.

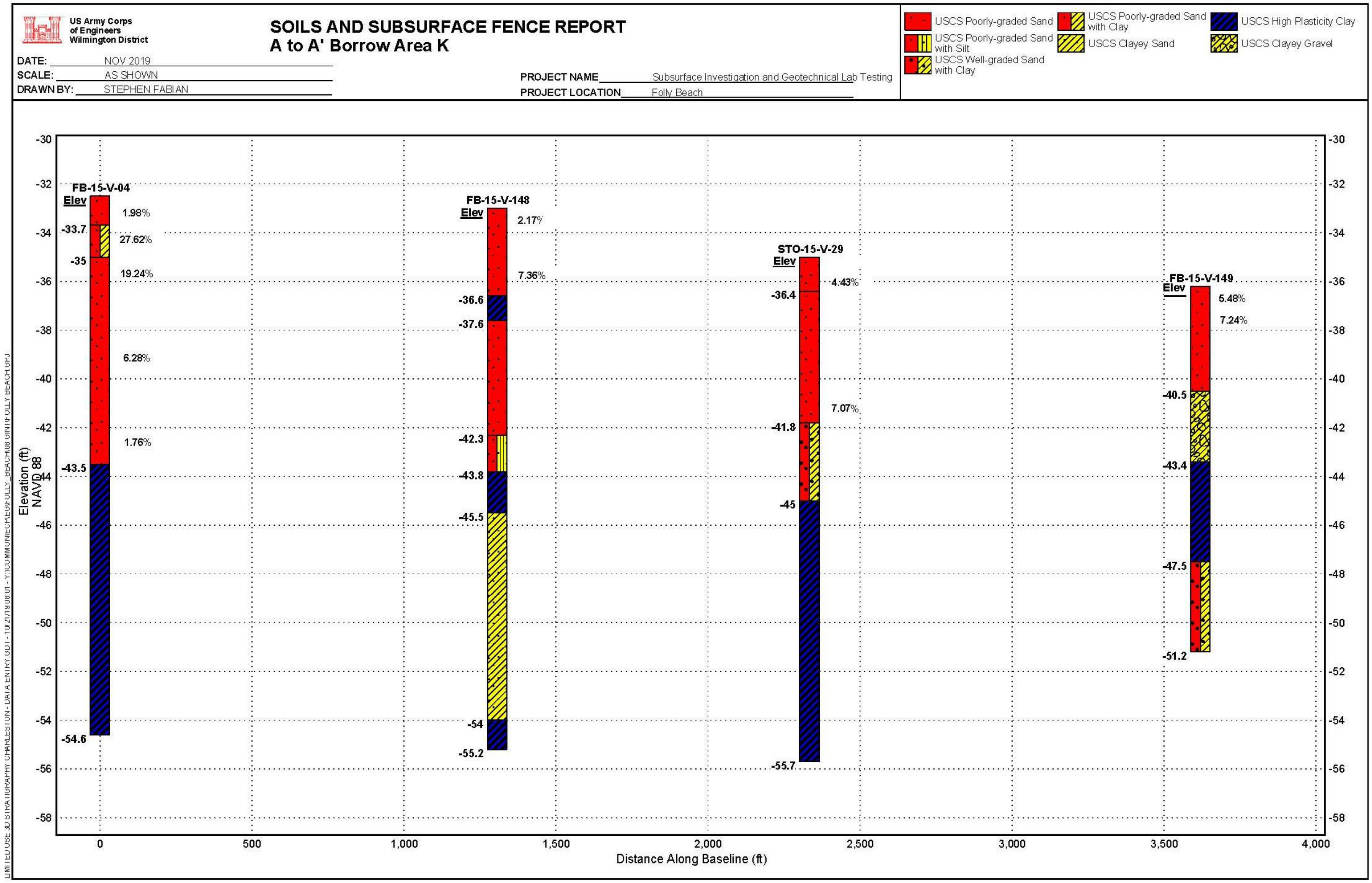

Figure 51. Fence diagram: A to A’ borrow area K.

7.0 INTRODUCTION OF VOLUMES AND OVERFILL RATIOS

Following an extensive quantitative and qualitative compatibility study for each borrow area, volumes and overfill ratios were calculated to determine if borrow areas contained enough beach compatible sand to support a 50-year project life. It is important to note that the volumes calculated in this document are not design-level volumes. These calculations are "rough" estimates ("insitu volume calculations") which used triangular irregular networks (TINs) rather than specific dredge-cut elevations coupled with bathymetric data. Bathymetric surveys would need to be performed over each borrow area to obtain more accurate volumes and additional vibracore investigations, in some areas, would be required to reduce spacing between core locations and increase suitability resolution.

Overfill ratios were determined for each borrow area. The overfill ratio is computed by numerically comparing the grain size distribution characteristics of the native beach sand with that of the borrow area, which includes a final adjustment for the percentage of fines within the borrow area. The purpose of the overfill ratio is to account for the natural loss due to winnowing of the borrow sediment that is finer than the native beach sediment. The overfill ratio is defined as the volume of borrow material required to produce a "stable" unit of suitable beach fill material that has the same grain size characteristics as the native beach (James, 1975). For example, an overfill ratio of 1.2 indicates that 1.2 units of borrow material will behave similarly to 1 unit of native beach fill. The overfill ratios were used to adjust template designs for each borrow area used.

7.1 METHODOLGY FOR VOLUME CALCULATIONS

After the suitable sand thicknesses were determined, following the guidelines outlined in section 4.0, a triangulated irregular network (TIN) was created within each borrow area as shown in sections 5.0 and 6.0. Once the TINs were created, vibracores were selected using the "select by attribute" function to identify vibracores containing greater than or equal to 3.0 ft of usable sand thickness[10] and less than 10% fines passing the No. 200 sieve. Once those vibracores were highlighted, a shapefile was drawn marking the boundary around those highlighted vibracores. This boundary was called the "preliminary dredge area" and was then overlain on the sand isopach TIN. The TIN was then clipped to the "preliminary dredge area". The clipped TIN was then used in the "surface volume tool" with the plane height set to 0. This method was used to determine the volume for each borrow area.[11] The volumes calculated from this procedure are known as the "insitu volumes". These volumes do not account for losses and assume 100% of the TIN created will be removed from the subsurface. To achieve more accurate volume estimates, bathymetric surveys, additional vibracores, and determining dredge-cut elevation depths would need to be performed.

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[10] After talking with Wilmington District supervisory personnel, it was determined that 3 ft of usable sand thickness would be used as minimum dredge-able requirement. Vibracores exhibiting greater than or equal to 3 ft of usable sand thickness were incorporated in the volume calculations. If vibracores showed isolated amounts or small concentrations of usable sand thicknesses the volumes were not calculated.

[11] Volume outputs in GIS ArcMap were in ft^3 due to the coordinate system being NAD83 South Carolina State Plane International Feet. The volume outputs were later converted from ft^3 to yd^3.

7.2 METHODOLGY OF OVERFILL RATIOS

Two methods were used to calculate overfill ratios for each borrow area. This process was performed to test the accuracy of each method and determine whether the methods yielded comparable results. The first method used was based on USACE's Technical Memorandum No. 60, *Techniques for Evaluating Suitability of Borrow Material for Beach Nourishment* (James, 1975). This document reviews various methods for determining overfill ratios, such as the Adjusted Fill Factor (AFF) method. This graphical method was used to develop the overfill ratios for each borrow area. Core composite statistics such as mean grain size, standard deviation, and percent fines of each core were determined. These calculations were then used to calculate the core composite X[12] values, Y[13]values, and silt correction factor. Once the X and Y values for each core were calculated, the cumulative mean X and Y values were then used in Figure 52 to determine an "initial overfill ratio"[14]. Using Figure 52, the point on the graph where the X and Y values intersected was the "initial overfill ratio."

The second method for overfill ratio calculations involved the Coastal Engineering Design and Analysis System (CEDAS). The CEDAS method is a computerized program that uses the same variables as the graphical method but considers the borrow area volume. The CEDAS software method uses the cumulative borrow means of the mean grain size and standard deviation, native mean grain size and standard deviation, and calculated "insitu" borrow area volume. Once the "initial overfill ratio" values for both of the graphical and software method were determined, one final adjustment was made, the "silt correction factor." This is defined mathematically by 1/1-(percent silt[15]/100). Once the "silt correction factor" was determined, the value was multiplied by the "initial overfill ratio" to obtain a final overfill ratio value for each specific borrow area. Each of the two methods yielded comparable results. Final overfill ratio values between the AFF and CEDAS method had a difference of 0.1 to 0.3. Because there is a possibility for error when plotting the overfill ratios using the AFF Method, the CEDAS overfill ratios were used for this report.

[12] X = [MEAN (PHI) BORROW – MEAN (PHI) NATIVE / STD. DEV. NATIVE (PHI)]
[13] Y = STD. DEV. (PHI) BORROW / STD. DEV. (PHI) NATIVE
[14] The "initial overfill ratio" does not consider the applied silt correction factor.
[15] Percent silt denotes the percent of sediment passing the No. 200 sieve.

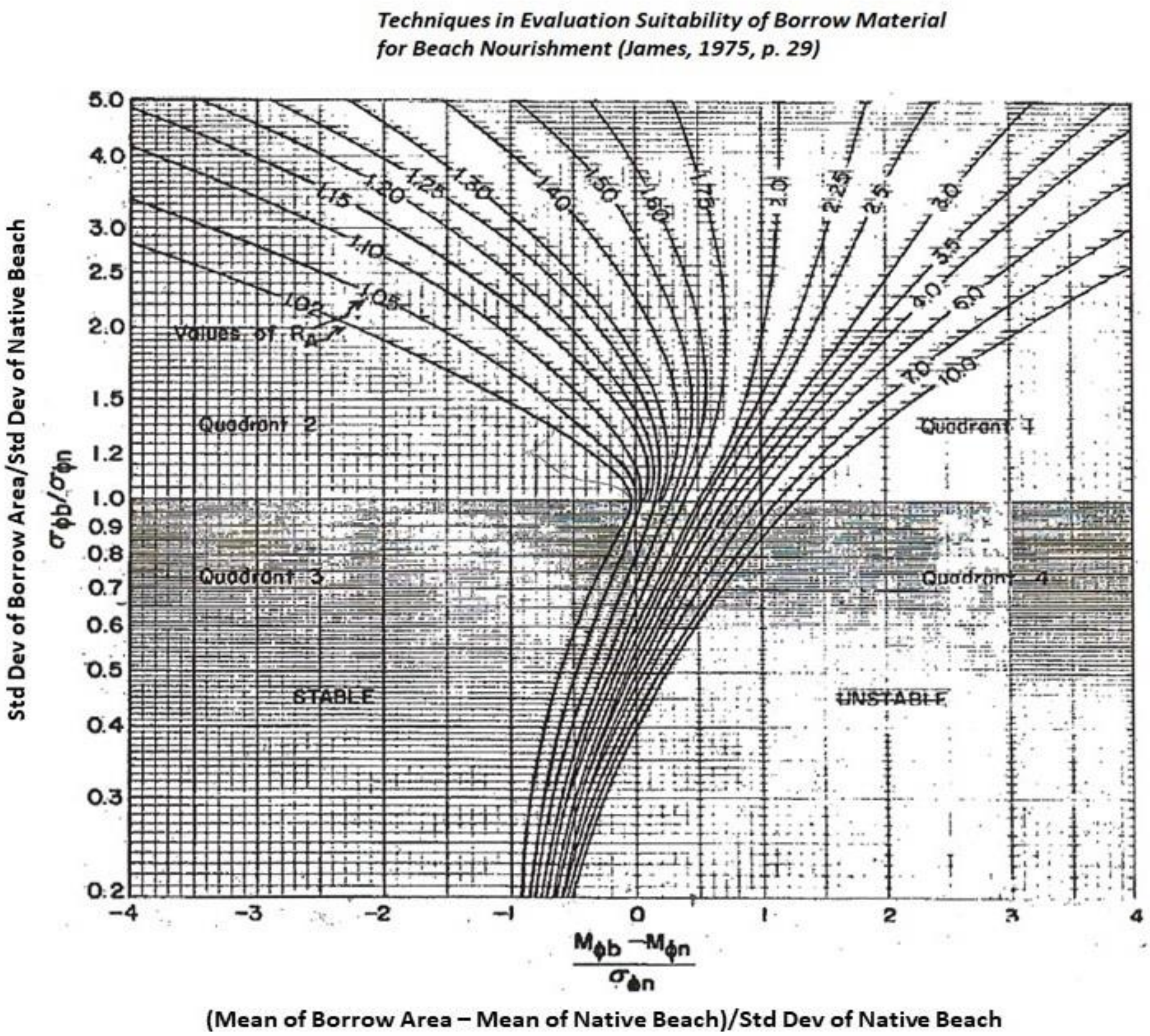

Figure 52. Adjusted Fill Factor Plot. After finding the cumulative mean X and Y values this graph was used to determine the “initial overfill ratio”.

7.3 VOLUME AND OVERFILL RATIO RESULTS

Table 4 provides a summary of volumes and overfill ratios for each borrow area.

Table 4. Grain size characteristics and volumes within preliminary dredge areas.

Borrow Location	CBRA Zone	Rechargeable	Pumping Distance (miles)	Passing No. 200 Sieve	Mean (mm)	Median (mm)	Overfill Ratios[16]	"Insitu" Volume yd^3 [17]
Folly River	Inside	YES	1-2	2.21	0.16	0.16	1.31	2,700,000[18]
Stono Ebb Shoal **(E)**	Outside	NO	4-7	3.80	0.23	0.19	1.17	14,000,000
Lighthouse Inlet **(F)**	Outside	NO	1-3	5.31	0.26	0.20	1.35	2,800,000
Central Folly **(G)**	Outside	NO	2-4	7.68	0.17	0.15	1.73	8,000,000
Seaward of State's Territorial Limits[19] **(H)**	Outside	NO	4-6	5.51	0.40	0.33	1.10	4,000,000
Stono Inlet Throat **(I)**	Inside	YES	2-4	2.60	0.18	0.17	1.16	9,100,000
Ebb Shoal 1 **(J)**	Inside	NO	3-5	5.52	0.14	0.13	1.71	3,400,000
Ebb Shoal 2 **(K)**	Inside	NO	4-6	6.23	0.23	0.17	1.32	800,000
Sullivan's Island	Outside	NO	9-12	4.75	0.20	0.17	1.41	5,000,000

[16] Software method was used to determine overfill ratios for each borrow area. Overfill ratios include the silt correction factor.
[17] Insitu volume was determined using the clipped, sand isopach TINs from a "preliminary dredge area". "Preliminary dredge areas" take into account areas containing greater than or equal to 3.0 ft of usable sand and core composites containing less than or equal to 10% fines passing the No. 200 sieve. These volumes do not account for overfill ratios and assume 100% of TIN will be removed and placed on the beach.
[18] Folly River is a rechargeable source that has been used for previous nourishments. Last nourishment was completed in 2018. Current volume in the Folly River did not take into account the removal of material from the 2018 nourishment.
[19] Volume calculations were not determined for potential borrow areas having five or less vibracores or failure of vibracores to produce a measureable polygon to calculate usable sand thickness volumes.

8.0 BORROW AREA IMPACT ANALYSIS

Following the geotechnical analysis and calculation of overfill ratios for each borrow area, the U.S. Army Engineer Research and Development Center (ERDC) performed a wave impact assessment on borrow areas E, F, G, I, J, and K.[20] ERDC found that excavating these borrow areas will in some way cause changes to the nearshore bathymetry, which will affect the wave transformation (Dillon, 2019). In order to complete their assessment, the STeady-state WAVE (STWAVE) model (Dillon, 2019) which is a phase-averaged spectral model for wave generation, propagation and transformation, was used to simulate wave transformation. The impact analysis assumed the removal of 10 ft from each borrow area. Based on the study ouputs, if the removal of material from a borrow area created an increase in wave heights along the shoreline, the borrow area was excluded from the 50-year project. As a result, borrow areas I and J showed increased wave heights to the nearshore. Therefore, these two borrow areas were removed from consideration, effectively making their volumes represent 0. Additional details of this report can be found in the Coastal Appendix.

9.0 EVALUATION OF BORROW AREAS

Several factors were considered when evaluating each borrow area including distance from shoreline, recharge-ability, location with respect to the CBRA zone, pumping distance from shore, grain size, usable volume, available vibracore data, and erosional impacts to nearby shorelines or shoals. This comprehensive analysis looked at each factor to prioritize each borrow area. The prioritization is as follows:

1) Borrow Area E. The quality and quantity of beach compatible sands in this area is the largest of any source. Over 10 million yd^3 are present in this borrow area. This area could be used for several nourishments and supply Folly Beach with initial construction and future periodic nourishments. Thick deposits of sand are present over a vast area with little to no unsuitable areas across the borrow area making it ideal dredge efficiency. The borrow areas is situated outside of the CBRA zone and would not require permission from USFWS. Also, dredging activities would not create erosional impacts to nearby shorelines or ebb shoals. However, one major drawback is the pumping distance to shore. In order to cover the project extents, pumping distances could reach up to 7 miles.

2) Borrow Area F. The quality of sands in this borrow area range from 0 to 10% fines. This is the closest borrow area to Folly Beach outside the CBRA zone. The distribution of beach compatible sands exists in the middle and northeast end of the borrow area. This borrow area could provide one to two periodic nourishments. Vibracore data in this area are spaced at 1,000 ft apart[21], and therefore, no additional geotechnical data would be needed. However, there are areas of unsuitable material present in the borrow area and the thickness of suitable sands vary. This could result in lower dredging efficiency and increase costs despite the sand source being close

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[20] Sullivan's Island and the Folly River were excluded from this study. In the future, the Folly River and possibly Sullivan's Island will under-go a more sophisticated borrow area impact analysis.
[21] This is a USACE engineering recommendation that requires vibracores to be spaced at least 1,000 ft from one another in order to commence dredging operations in a borrow area.

to shore. Additionally, water depths within this borrow area are relatively shallow and a smaller dredge would need to be used, which then would impact the production efficiency.

3) Folly River. This area has been used multiple times for nourishments. Grain sizes within this site are beach compatible and are thick and uniform with very fine to fine grained sand. The grain size within this borrow area is slightly finer than the native beach. The closeness of this borrow area to Folly Beach and its location protects the area from high wind and wave events making it ideal for dredging production. Additionally, this area is rechargeable and can be used again if given enough time to accumulate shoaled material from adjacent barrier islands and ebb shoals. However, this area exists in a CBRA zone and might require exemption from this regulation.

4) Borrow Area G. This borrow area's proximity and location relative to the shoreline provides easy access to reach the project extents. Also, this borrow area exists outside the CBRA zone and the borrow area impact analysis showed no erosional impacts to the shoreline if dredged. Most of the vibracores are spaced 1,000 ft apart, and the thickest sands are found in the northeastern end. The drawback to this borrow area is its high fines content and the small mean grain size. The fines content in this borrow source ranges from 5 to 15% and mean grain sizes are slightly lower than the native beach grain size. With very fine to fine grained sands and a high percentage of fines, the dredging efficiency in this borrow area would be lower than expected. Because the material is very fine-grained, getting material placed on the beach could be a challenge. Moreover, once the very fine to fine grained sands are placed, if repeated storms were to impact Folly Beach following the nourishment, the placed material would not remain.

5) Borrow Area K. This area has the second highest fines content among the nine borrow areas and the smallest volume of any borrow area. The limited volume of usable sand in this area would not provide enough material for initial construction or periodic nourishment. This area and possibly one other borrow area would need to be used to provide enough material to complete initial construction or periodic nourishment. Given that the area would not supply enough for initial construction or periodic nourishment, the dredge would have to mobilize to another borrow source, which would result in increased dredging costs. Alternatively, this area could be used for an emergency nourishment following major storms. The borrow area is in the CBRA zone and may require CBRA exemption if used. The borrow area impact analysis did not show impacts to the neighboring shorelines and pumping distances would be manageable.

6) Borrow Area H. This is the furthest borrow area offshore Folly Beach. Pumping distances could reach up to 9 miles to cover the extents of the project. Grain size data show fines content from 2 to 10% with fine to medium grained sands. This borrow area appears to have enough beach compatible sands to supply initial construction or periodic nourishment, but the spacing between the vibracores is greater than 1,000 ft. Additional vibracores would need to be taken in this area to reduce spacing and to get a better sense of the quantity of material present.

7) Sullivan's Island. This borrow area contains less than 5% fines and has generally the same native mean grain size as Folly Beach. Also, it has the potential to recharge given enough time for longshore sediment transport to carry sands downdrift. The borrow area is outside the CBRA zone and would not require an exemption. However, several caveats could hinder the use of this source. The borrow area's proximity to shore would require a borrow area impact analysis to determine if any potential impacts would be experienced by Sullivan's Island. Also, pumping distances could reach up to 12 miles to cover the extents of the project. In additon, pipeline routes would have to cross the entrance into Charleston Harbor making it problematic for port traffic. Using this borrow area could come at a great financial cost which could be too high to justify. Lastly, the vibracore spacing in this area is greater than 2,000 ft and would require additional sampling.

8) Borrow Area I. This area has significant volume of beach compatible sands that would be able to provide adequate material for initial construction and periodic renourishment. This area is also likely to recharge and could be used more than once. Also, its proximity to the shoreline makes it ideal for covering the project extents. Grain sizes resemble the native beach and fines content is less than 3%. However, the borrow area impact analysis showed negative impacts to neighboring shoals and shorelines if this area were to be used for nourishment. As a result, this borrow area cannot be used for the 50-year project.

9) Borrow Area J. This borrow area has enough beach compatible sands to supply initial construction or periodic nourishment. This area is also likely to recharge and could be used more than once over the life of the project. Grain sizes resemble the native beach, and fines content is less than 3%. However, the borrow area impact analysis showed negative impacts to neighboring shoals and shorelines if this area were to be used for nourishment. As a result, this borrow area cannot be used for the 50-year project.

In summary, given the factors evaluated, the borrow area prioritization could change if 1) CBRA restrictions are not applied, 2) borrow area impact analyses indicate minimal erosion to neighboring shorelines and shoals, or 3) the cost effectiveness of using a specific borrow area changes. Table 5 provides volumes for each borrow area over the 50-year project life.

10.0 FUTURE BORROW SOURCE DELINEATION

After delineation and evaluation of each borrow area, additional areas that may yield suitable resources for future nourishments were identified. These areas would require new vibracores for further delineation. Several areas seaward of the state's territorial seas limit were identified. Four of the areas are adjacent to borrow area E, where clusters of vibracores indicate greater than 6.0 ft of usable sand. However, additional vibracores would need to be taken to determine measurable volumes. Another area is adjacent and within borrow area H. Additional vibracores within borrow area H would need to be performed to provide tighter spacing to ensure suitable material is continuous throughout the borrow area. Also, the northwestern and eastern portions of the borrow area show some indication of thicker sands, but additional vibracoring is also needed.

Another area of interest is adjacent to borrow area F, which is downdrift of Lighthouse Inlet. The northeastern end has the thickest deposits of usable sands. Taking additional vibracores to the northeast, closer to Lighthouse Inlet, may require an exemption from CBRA. This area likely yields thick sand deposits from the ebb shoals of Lighthouse Inlet. The last area of interest is north of Folly Beach and is located offshore of Sullivan's Island. Vibracore investigation in 2019 covered a small area offshore Sullivan's Island. An additional vibracore effort with tighter spacing and updrift of updrift of Charleston Harbor could yield additional volumes for this borrow area. Figure 53 shows the areas that could yield additional sand for the 50-year project life.

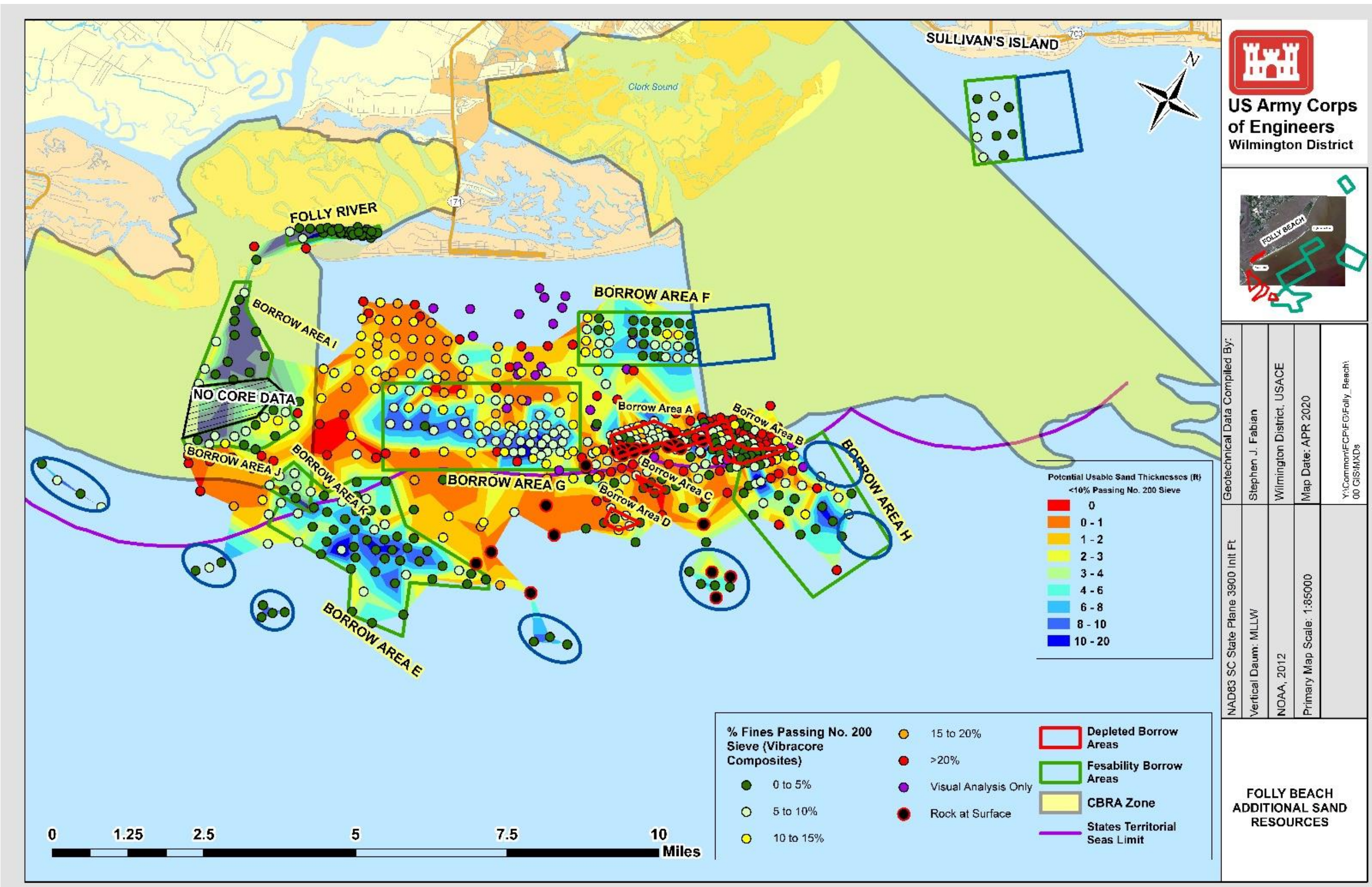

Figure 53. Potential areas of additional sand resources are outlined in dark blue. These areas could yield additional sands for nourishment provided additional vibracores are taken and exemption from CBRA remains.

11.0 CONCLUSIONS

The borrow area outside the CBRA zone with the coarsest sands and lowest overfill ratios are borrow areas E and H. These two areas contain the most suitable sands relative to the other borrow areas in and outside the CBRA zone. The overfill ratios within both of these areas range from 1.10 to 1.17. Looking closer to shore, outside CBRA, and within the state's territorial seas limit, very fine to fine-grained sands are present. The average fines content ranges from 5% to 15% and overfill ratios are considerably higher, ranging from 1.35 to 1.73. Although the areas are close to shore and using them might be cost-effective with respect to dredging and material transport, the respective sand quality is fine-grained.

Borrow areas within the CBRA zone indicate suitable beach-fill. Mean grain sizes range from 0.17 mm (Folly River) to 0.23 mm (borrow area K) with percent fines ranging from 2.20% (Folly River) to 6.23% (borrow area K). Overfill ratios range from 1.16 (borrow area I) to 1.71 (borrow area J). The ideal borrow area among the four in CBRA is borrow area I; its mean grain size of 0.18 mm (2.47 phi) and has the lowest overfill ratio of 1.16. However, the proximity to the critical habitat for nesting shorebirds and its closeness to Folly Beach and Kiawah Island raises concern. A wave impact analysis completed by ERDC rules out this area because the removal of this material would cause significant wave impacts to the surrounding area. Therefore, the volume is not accounted for and this area is off limits for dredging.

From the extensive sand search, several areas have been identified to be suitable for beach placement. However, potential CBRA restrictions and a location greater than 4 miles offshore may prevent utilization for beach nourishment, due to cost effectiveness. If CBRA restrictions are upheld and federal spending is prohibited in these areas, the total potential yd^3 is greatly reduced. Under the assumption that CBRA borrow areas are off limits and borrow areas seaward of the three nautical-mile-line are too far away, reducing cost effectiveness, the Folly Beach project can expect an 80% reduction in available nourishment material, from 38,000,000 yd^3 to only 7,000,000 yd^3. These setbacks greatly reduce potential yardage and pigeonhole Folly Beach into using the less suitable borrow areas G and F. Using these two borrow areas stretches the limits for usable sand and considers utilizing sands containing up to 12 to 15% fines for beach placement.

Following economic, coastal, and cost analysis, four borrow areas were identified to support the 50-year project. Borrow areas E, F, K, and Folly River were identified to fulfill the 50-year demand (Figure 54). However, recent CBRA interpretations (2021) will disallow the federal project to use the Folly River and Area K for nourishment purposes. If CBRA is reinterpreted to allow the Folly River to be used this borrow area will be considered for utilization. In order to meet project placement demands for initial construction and periodic nourishments Areas F and E will be used. Area F will be used for initial construction and Area E will be used for three other periodic nourishments thereafter.

Although these four borrow, E, F, K, and Folly River are feasible, geotechnically three out of the four borrow areas are coarser than the native beach of Folly with fines content ranging from 2% to 6%. Placing coarser sands relative to the native beach may result in higher stand-up of fill and steeper beach profile following the placement of fill. This could result in an atypical beach profile where there is a steep transition from the dune to the foreshore. In contrast, placing finer sands may result in in excessive sand migration offshore and flattening of the beach profile. This would make the current beach more vulnerable to over wash. Maintaining the natural beach profile of dune, berm, and gentle slope can be difficult in this environment given large tidal fluctuations and the frequent impacts from sub-tropical and tropical storms. In an attempt to mitigate an atypical beach profile applying overfill ratio to the final beach template will assist in this engineered beach to behave to the natural environment. Borrow areas which contain finer grain sizes will require additional placed material to the final beach template while coarser sands will require little change to the final beach template.

Overall maintaining the typical beach profile not only relies on grain size but also the final design of the beach template. Having too high or low of a construction berm or too steep or shallow of a slope into the foreshore can result in an atypical beach profile. Modeling of shoreline change and overall sediment budget will assist in developing the most protective and least erodible beach template. Development of the beach template and adequate grain size placed on the beach go “hand in hand.” Moreover, having the grain size resembling the native may not keep a typical beach profile if the beach template is poorly engineered. Vice versa, if the grain size does not resemble the native beach but the template is engineered appropriately a typical beach profile may not be kept.

Before each construction to ensure adequate material is still in-place additional vibracores will need to be collected during the pre-engineering design (PED) phase. Following the collection of additional vibracores, initial construction will utilize borrow area F followed by nourishment from the Folly River, then from borrow areas E and K, and then back to Folly River. Total beach placement volume will be around 8.5 million yd^3 over the 50 years. Presently, among the borrow areas to be used, the in-place cumulative borrow area volume exceeds 15 million yd^3.

The continued fight in maintaining coastal protection will be ongoing for Folly Beach given the fine-grained nature of sands used for nourishments and the increased frequency and intensity of tropical systems. Frequently nourishing Folly Beach by using coarser sands similar to the native beach and utilizing borrow sources both in and outside of CBRA zones will help mitigate shoreline erosion and sustain a 50-year project life. Table 5 provides a summary of the quality and quantity of sand over the 50-year project life.

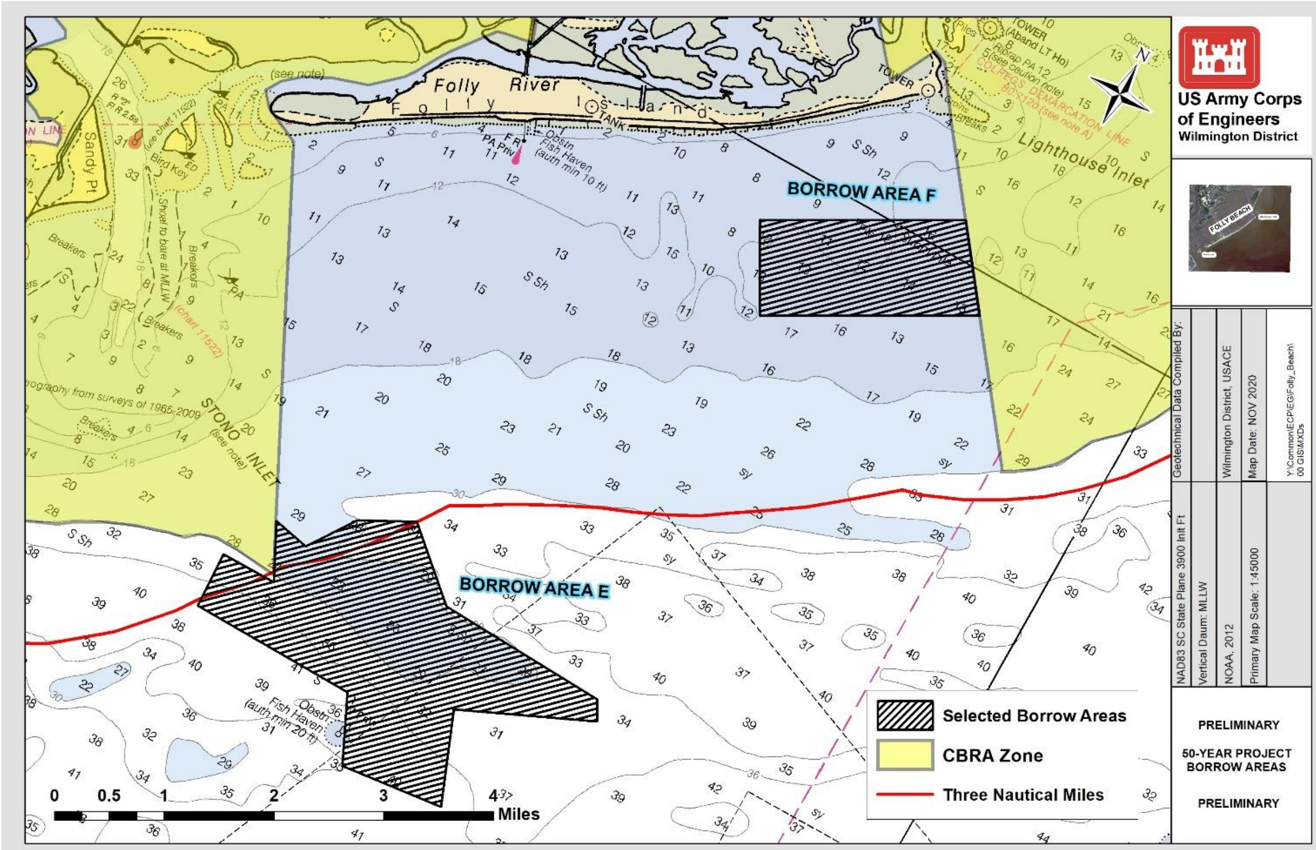

Figure 54. Borrow areas selected for the 50-year project.

Table 5. Final borrow area volume over the 50-year project life[22].

Borrow Location	CBRA Zone	Rechargeable	Impactful to Shoreline	Depth Ranges[23]	Pumping Distance (miles)	Passing No. 200 Sieve	Mean (mm)	Median (mm)	Overfill Ratios[24]	"Insitu" Volume[25] yd^3	"Insitu Volume Over 50 Years
Folly River	Inside	YES	UNKNOWN	-5 to -12	1-2	2.21	0.16	0.16	1.31	2,700,000	13,000,000[26]
Stono Ebb Shoal **(E)**	Outside	NO	NO	-30 to -40	4-7	3.80	0.23	0.19	1.17	14,000,000	14,000,000
Lighthouse Inlet **(F)**	Outside	NO	NO	-10 to -15	1-3	5.31	0.26	0.20	1.35	2,800,000	2,800,000
Central Folly **(G)**	Outside	NO	NO	-20 to -30	2-4	7.68	0.17	0.15	1.73	8,000,000	8,000,000
Seaward of State's Territorial Limits **(H)**	Outside	NO	NO	-30 to -40	4-6	5.51	0.40	0.33	1.10	4,000,000	4,000,000
Stono Inlet Throat **(I)**	Inside	YES	YES[27]	0 to -30	2-4	2.60	0.18	0.17	1.16	0	0
Ebb Shoal 1**(J)**	Inside	NO	YES	0 to -20	3-5	5.52	0.14	0.13	1.71	0	0
Ebb Shoal 2 **(K)**	Inside	NO	NO	-20 to -30	4-6	6.23	0.23	0.17	1.32	800,000	800,000
Sullivan's Island	Outside	NO	UNKNOWN[28]	-10 to -15	9-12	4.75	0.20	0.17	1.41	5,000,000	5,000,000
											38,000,000[29]

[22] The borrow area volumes are NOT final. Additional bathymetric data, vibracores, and formulation of dredge depth plans need to be developed in order to determine final "insitu" volumes. The volumes presented are estimates for what is "insitu" for each vibracore's sand thickness.
[23] Borrow area depth ranges are in MLLW
[24] Software method was used to determine overfill ratios for each borrow area. Overfill ratios include the silt correction factor.
[25] Insitu volume was determined using the clipped, sand isopach TINs from a "preliminary dredge area". "Preliminary dredge areas" take into account areas containing greater than or equal to 3.0 ft. of usable sand and core composites containing less than or equal to 10% fines passing the No. 200 sieve. These volumes do not account for overfill ratios and assume 100% of TIN will be removed and placed on the beach.
[26] Assumes a recharge rate of 12.5% per year and 2,000,000 yd^3 being taken out and recharged completely in 8 years. Also, the volume assumes that removing 2 million yd^3 from the Folly River will not have impacts to neighboring shorelines or shoals.
[27] Utilization of this borrow area would increase wave heights significantly enough to impact the shoreline and cause erosion to nearby shorelines and sand shoals. The borrow areas volume is NOT added to the 50-year project life, applies to Stono Inlet Throat and Ebb Shoal 1.
[28] Until this area has a borrow area impact analysis complete the "impactful to shoreline" will remain unknown. The volumes associated with this borrow area will assume that it is acceptable to use and no shoreline impacts will occur.
[29] The sum of the insitu volume over 50 years applied a mechanical loss factor of 20%. Mechanical losses use the difference in volume taken out of the borrow area versus placement volume on the beach. The Folly River and depleted borrow areas A, B, C, and D both had mechanical losses of 20%.

12.0 REFERENCES

Bodge, K.R., 2006, Alternative computation of Dean's overfill ratio: *Journal of Waterway, Port, Coastal, and Ocean Engineer*ing (ASCE), vol. 132, no. 2, p. 133-138.

Cleary, W.J. and Pilkey, O.H., 1996, Environmental coastal geology: Cape Lookout to Cape Fear, North Carolina regional overview. In: W.J. Cleary (ed.), Carolina Geological Society Field Trip Guidebook 1996, pp. 89-138.

Colquhoun, D.J., 1969, Geomorphology of the Lower Coastal Plain of South Carolina: Division of Geology, South Carolina State Development Board, Report MS-15, 36 p.

Davis, R.A., Jr. and Fitzgerald, D.M., 2003, Beaches and coasts (illustrated edition): Wiley-Blackwell p.131-166.

Dean. R.G., 1991, Equilibrium beach profiles: characteristics and applications, *Journal of Coastal Research*, vol. 7, pp. 53-84.

Dean, R.G., 2002, *Beach Nourishment: Theory and Practice*, World Scientific Press, New Jersey, 399 p.

Dillon, S.C., 2019, Effects of five potential borrow areas on wave propagation at Folly Beach, South Carolina, U.S. Army Engineer Research and Development Program.

Gayes, P.T., Donovan-Ealy, P., Harris, M.S., and Baldwin, W., 1998, Assessment of beach re-nourishment resources on the inner shelf off Folly Beach and Edisto Island, South Carolina: Center for Marine and Wetland Studies, Coastal Carolina University, Final Report of the South Carolina Task Force on Offshore Resources to the Minerals Management Service Office of International Activities and Mineral Resources, 43 p.

Gayes, P.T., Hill, J., Viso, R., Okano, S., Phillips, J., and Johnson, B., 2015, Geophysical study of the inner shelf in the vicinity of Stono Inlet South Carolina: Generated for the U.S. Army Corps of Engineers by the Center for Marine and Wetland Studies, Coastal Carolina University.

GDM, 1991, General Design Memorandum: Folly Beach, South Carolina, Shore Protection Project, U.S. Army Corps of Engineers.

Harris, M.S., Gayes, P.T., Kindinger, J.L., Flocks, J.G., Krantz, D.E., and Donovan, P., 2005, Quaternary geomorphology and modern coastal development in response to an inherent geologic framework: an example from Charleston, South Carolina: *Journal of Coastal Research*, vol. 21, no. 1, pp. 42-64.

Horton, J.W., Jr. and Zullo, V.A., 1991, Geology of the Carolinas, Carolina Geological Society 50th Anniversary Volume: Knoxville, TN, University of Tennessee Press, 406 p.

James, W.R., 1975, Techniques in evaluating suitability of borrow material for beach nourishment: Technical Memorandum no. 60, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, VA, 82 p.

Katuna, M.P., Geisler, J.H., and Colquhoun, D.J., 1997, Stratigraphic correlation of Oligocene marginal marine and fluvial deposits across the middle and lower coastal plain, South Carolina: Sedimentary Geology, v. 108, pp. 181-194.

McCartan, L., Owens, J.P., Blackwelder, B.W., Szabo, B.J., Belknap, D.F., Krizusaukul, N., Mitterer, R.M., and Wehmiller, J.F., 1982, Comparison of amino acid racemization geo-chronometry with lithostratigraphy, bisotratigraphy, uranium-series coral dating, and magnetostratigraphy in the Atlantic Coastal Plain of the southeastern United States: *Quaternary Research*, vol. 18, pp. 337–359.

Schwab, W.C., Gayes, P.T., and Denny, J.F., 2002, Preliminary interpretation of USGS geophysical survey off Folly Beach, SC: sampling strategy for sand resource investigation: United States Department of the Interior Geological Survey.

Schwab, W.C., Gayes, P.T., Morton, R.A., Driscoll, N.W., Baldwin, W.E., Barnhardt, W.A. (ed), Denny, J.F., Harris, M.S., Katuna, M.P., Putney, T.R., Voulgaris, G., Warner, J.C., and Wright, E.E., 2009, Coastal change along the ahore of Northeastern South Carolina–The South Carolina Coastal Erosion Study: US Geological Survey Circular 1339, 77p.

USACE PIR, 2013, Project Improvement Report, Rehabilitation Effort for the Folly Beach Shore Protection Project: U.S. Army Corps of Engineers, Charleston District.

Weems, R.E. and Lemon, E.M., Jr., 1993, Geology of the Carolinas, Charleston, Fort Moultrie, and North Charleston Quadrangles, Charleston and Berkeley Counties, South Carolina: USGS, Miscellaneous Investigation Series, Map I-1935, 1:24,000, 2 sheets.

Weems, R.E. and Lewis, W.C., 2002, Structural and tectonic setting of the Charleston, South Carolina region; evidence from the Tertiary stratigraphic record: Geological Society of America Bulletin, vol. 114, pp. 24-42.