An Evaluation of Optimal Seismic Line Spacing and Placement for Delineating Design Level Offshore Sand Resource Areas

by
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INTRODUCTION

The goal of this study was to characterize the sand resource within the F1 area based on the new seismic and core data collected by Chicago Bridge and Iron (CB&I) and detail the efficacy of the design level survey completed by CB&I. Area F1 is located approximately 6.3 nautical miles offshore of Toms River Township, Ocean County New Jersey (fig. 1). This project conducted an analysis of both the reconnaissance data collected in 2015 and the design level data collected in 2016 by CB&I for the Bureau of Ocean Energy Management (BOEM) as part the Atlantic Sand Assessment Project. There were six reconnaissance level CHIRP sub-bottom seismic lines and two reconnaissance level vibracores collected in F1. The design level survey of F1 consisted of 97 CHIRP sub-bottom seismic lines collected in a northwest- southeast orientation at approximately 30-meter spacing. Geologic data was collected from 31 locations in the form of 20-foot vibracores (fig. 2).

METHODS

The CHIRP data analyzed in this study was collected by CB&I using an EdgeTech™ SB-0512i 3200 High Penetration Sub-Bottom Profiler. SonarWiz™7 software was used to analyze the seismic and vibracore data. Sand reflectors were traced where the base of the sand reflector is evident in the seismic profile. The sand reflectors were traced by only one person to maintain consistency. Vibracore data was analyzed and plotted onto the seismic profiles to ground-truth the reflector that delineates the base of sand. The thickness of the sand in each seismic line was calculated in SonarWiz™7 by converting the two-way travel time from the seafloor to the base of the sand assuming an acoustic velocity of 1750 meters per second into an XYZ text file where Z represented sand thickness in feet. The data was then imported into Surfer™12 software to create sand thickness isopach maps and calculate sand volumes. The isopach maps created in Surfer™12 were blanked at the 5-foot thickness contour to only provide a volume for the shoal areas that were greater than five feet thick. The sand volumes calculated in Surfer™12 are in cubic feet and converted to cubic yards for use by client agencies.

To determine the most efficient line spacing for a design level survey a center fix point in the shoal was chosen. Seismic line NJ_DL_331 was chosen as the center fix point as it was located directly in the center of all the data collected over area F1. In consultation with BOEM and a NJDEP statistician it was originally decided to calculate volumes for differing line spacings outward from the center fix point until a 10% variation from the original calculated volume was reached. This variation was reached in tighter line spacings than expected so calculations were continued for increased line spacings. A trend in the data showed that line spacing was not the only factor affecting the variation. Line placement and the data coverage of both the flanks and center of the shoal also affected the amount of variation in the sand volume calculations.

The 60-meter line spacing was attained by choosing every other line from the center fix point (fig. 4) and using those lines to determine a volume of sand (fig. 5). For the next calculation, 90-meter spacing, every third line was chosen and used to calculate the volume of sand. This process was repeated for every 4th line form the center point (120-meter spacing), 5th line (150-meter spacing), etc. Due to each line being spaced 30 meters apart, each new iteration would increase the line spacing by 30 meters. This was completed for line spacing out to 480 meters. Beyond this line spacing volume calculations were only conducted for line spacings that had full flank and center coverage of the shoal, due to the noticed trends in the data showing the importance line placement has on the volume calculation.

The volumes calculated using the selected lines of a certain spacing were compared to the volume calculated at 30-meter spacing. This original volume was calculated using all 97 seismic lines and was considered the control for the experiment. A comparison of the original calculated volume to a volume calculated using only vibracore data and no seismic data was also conducted (fig. 18). The location of each vibracore and the thickness of sand was imported into Surfer™12 as an XYZ text file.

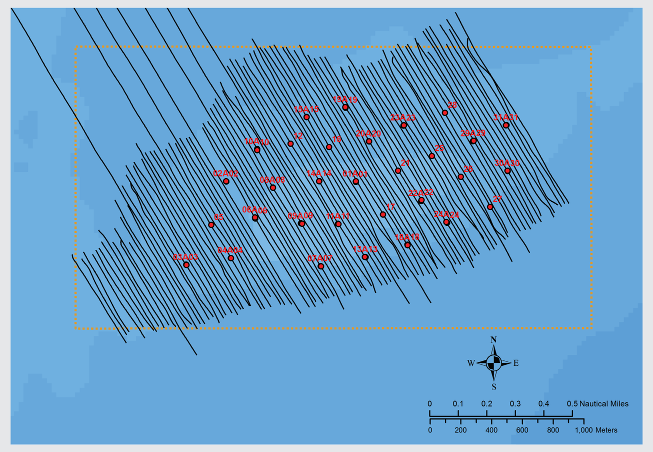
Figure 2: Locations of all 97 seismic lines collected at 30-meter spacing and the 31vibracore locations. Orange dashes outline area of figure 3 below.

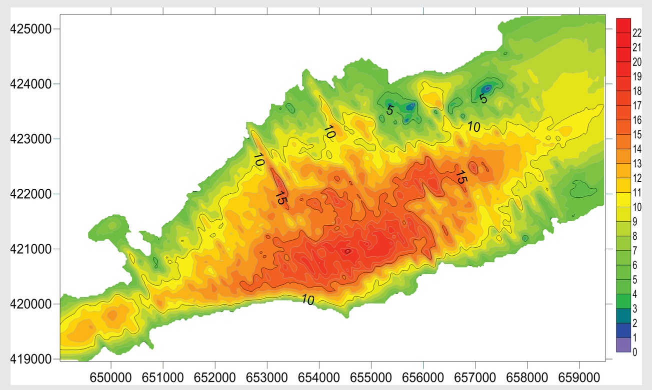
Figure 3: Isopach map created in Surfer™12 using data from all 97 seismic lines collected at 30-meter spacing. Isopach was blanked at the 5-foot contour. Thickness shown in feet. Coordinates in New Jersey State Plane Feet.

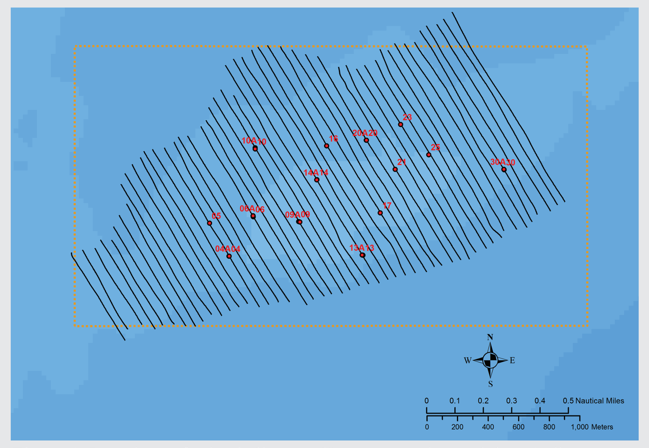
Figure 4: Locations of seismic lines at 60-meter spacing and the 14 vibracores located on those lines.Orange dashes outline area of figure 5 below.

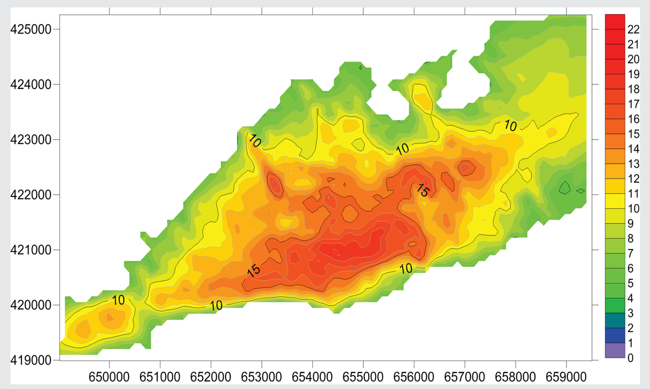
Figure 5: Isopach map created in Surfer™12 using data from seismic lines at 60-meter spacing. Isopach was blanked at the 5-foot contour. Thickness shown in feet. Coordinates in New Jersey State Plane Feet.

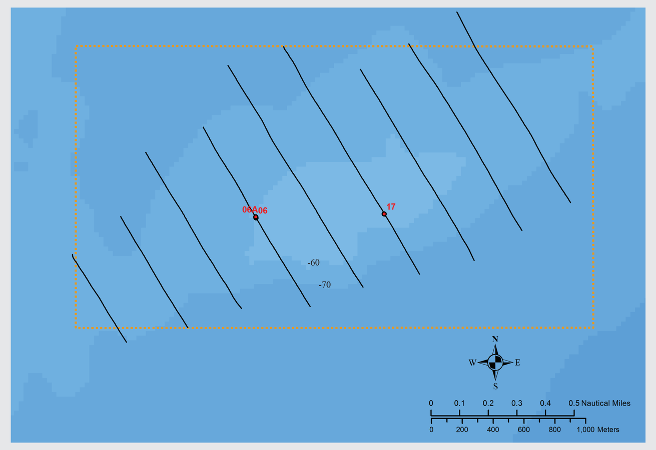
Figure 6: Locations of seismic lines at 360-meter spacing and the 2 vibracores located on those lines. Orange dashes outline area of figure 7 below.

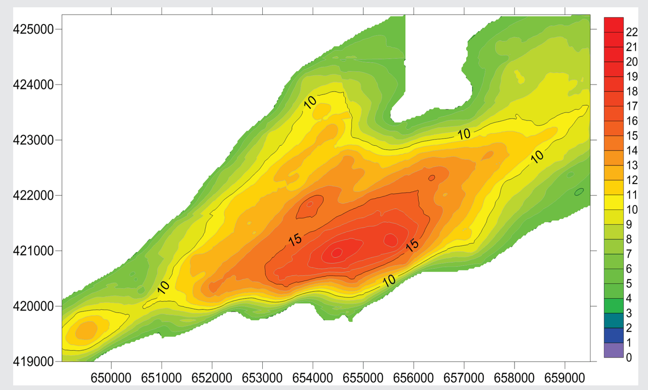
Figure 7: Isopach map created in Surfer™12 using data from seismic lines at 360-meter spacing. Isopach was blanked at the 5-foot contour. Thickness shown in feet. Coordinates in New Jersey State Plane Feet.

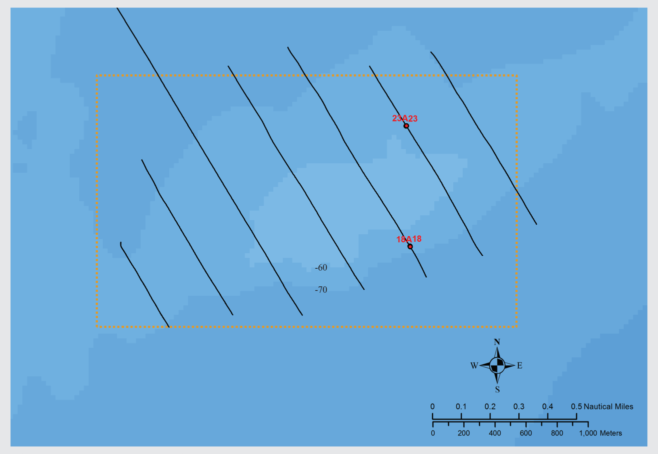
Figure 8: Locations of seismic lines at 390-meter spacing and the 2 vibracores located on those lines. Orange dashes outline area of figure 9 below.

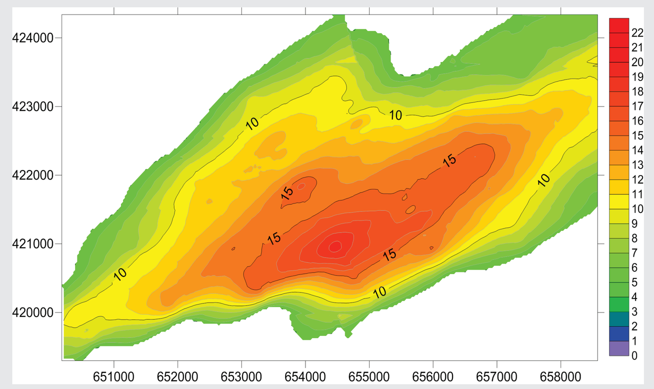
Figure 9: Isopach map created in Surfer™12 using data from seismic lines at 390-meter spacing. Isopach was blanked at the 5-foot contour. Thickness shown in feet. Coordinates in New Jersey State Plane Feet.

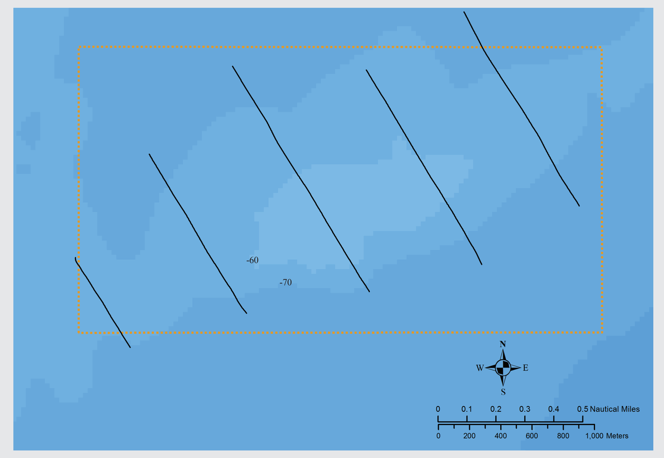
Figure 10: Locations of seismic lines at 720-meter spacing. No vibracores were located on these lines. Orange dashes outline area of figure 11 below.

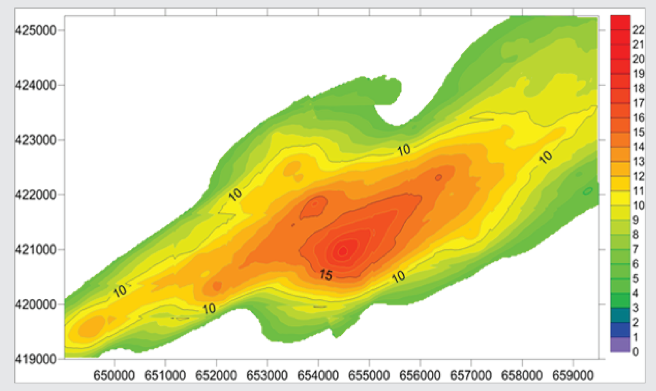
Figure 11: Isopach map created in Surfer™12 using data from seismiclines at 720-meter spacing. Isopach was blanked at the 5-foot contour. Thickness shown in feet. Coordinates in New Jersey State Plane Feet.

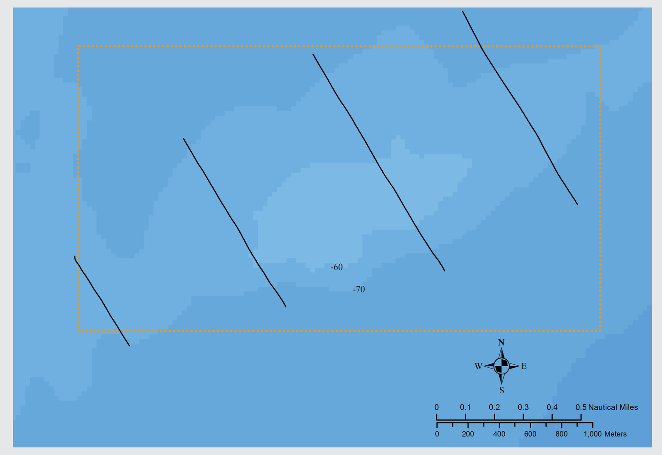
Figure 12: Locations of seismic lines at 960-meter spacing. No vibracores were located on these lines. Orange dashes outline area of figure 13 below.

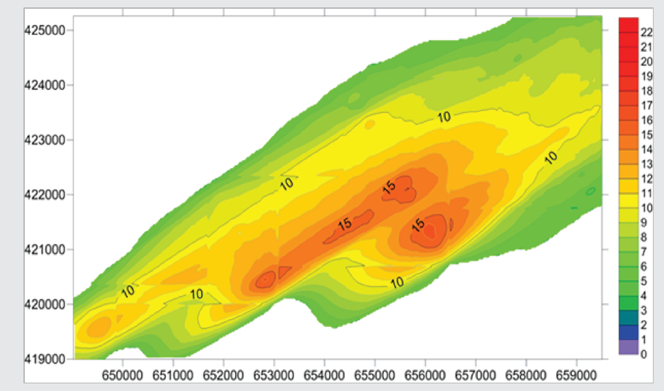
Figure 13: Isopach map created in Surfer™12 using data from seismic lines at 960-meter spacing. Isopach was blanked at the 5-foot contour. Thickness shown in feet. Coordinates in New Jersey State Plane Feet.

Data Used	Volume Cu/Ft	Volume Cu/Yds	% of Original Volume	% Variation from Original Volume	# of Lines Used	# of Cores on Lines	Approx. Line Spacing (meter)	Approx. Line Spacing (mi)	Approx. Line Spacing (nm)
All Lines	412,726,420	15,286,148	100.0%	0.0%	97	31	30	0.02	0.02
2nd	403,745,214	14,953,511	97.8%	2.2%	49	14	60	0.04	0.03
3rd	408,720,053	15,137,765	99.0%	1.0%	33	9	90	0.06	0.05
4th	407,584,142	15,095,694	98.8%	1.2%	25	11	120	0.07	0.06
5th	383,661,066	14,209,655	93.0%	7.0%	19	9	150	0.09	0.08
6th	415,322,695	15,382,307	100.6%	0.6%	17	3	180	0.11	0.10
7th	371,257,167	13,750,252	90.0%	10.0%	13	3	210	0.13	0.11
8th	399,970,398	14,813,704	96.9%	3.1%	13	1	240	0.15	0.13
9th	363,911,395	13,478,186	88.2%	11.8%	11	3	270	0.17	0.15
10th	363,044,788	13,446,090	88.0%	12.0%	9	5	300	0.19	0.16
11th	373,105,558	13,818,711	90.4%	9.6%	9	2	330	0.21	0.18
12th	413,349,275	15,309,217	100.2%	0.2%	9	2	360	0.22	0.19
13th	338,969,732	12,554,422	82.1%	17.9%	7	2	390	0.24	0.21
14th	364,918,542	13,515,488	88.4%	11.6%	7	1	420	0.26	0.23
15th	391,169,500	14,487,745	94.8%	5.2%	7	1	450	0.28	0.24
16th	405,395,623	15,014,638	98.2%	1.8%	7	0	480	0.30	0.26
24th	414,004,104	15,333,470	100.3%	0.3%	5	0	720	0.45	0.39
32nd	414,163,631	15,339,378	100.3%	0.3%	4	0	960	0.60	0.52
48th	465,567,397	17,243,220	112.8%	12.8%	3	0	1440	0.89	0.78
Recon	354,101,794	13,114,868	85.8%	14.2%	5	2			
Cores	341,365,143	12,643,141	82.7%	17.3%	0	31			

Table 1: F1 sand volume comparisons computed in Surfer™ 12 for different distances between seismic lines.

RESULTS

The sand volume calculated using all 97-design level seismic lines and 31 vibracores was 15,286,148 cubic yards. This volume was calculated using all the available data in this study so it is the most accurate representation of the real-life sand volume of F1 and will be referred to throughout this study as the original calculated volume. As shown in Table 1, calculations using seismic lines spaced at 60, 90 and 120 meters resulted in minimal variation from the original calculated volume. Greater amounts of variation were seen in line spacings of 150 meters and 210 meters but the variation did not surpass 10% which was set as the variation limit. Line spacing of 270 meters gave a variation of 11.8% from the original calculated volume, surpassing the limit of 10% variation. As stated in the methods, calculations were continued for even greater line spacings. Table 1 shows that for some line spacings greater than 270 meters, the percent variation from the original calculated volume fell below 1%. Such findings suggest that another factor besides line spacing was influencing the calculation. This factor was found to be the placement of the lines. The line spacings that resulted in incomplete coverage of the shoal, particularly the flanks, were found to be the instances that gave the larger amounts of variation from the original calculated volume. Line spacings of 360 (fig. 6), 480, 720 and 960 meters used seismic lines that covered the full extent of the shoal and all yielded minimal amounts of variation from the original calculated volume. Line spacings of 270, 300, 390 (fig. 8) and 420 meters did not have full coverage of the flanks of the shoal and were shown to have the greatest amount of variation from the original calculated volume. Line spacings of 330 and 450 meters consisted of seismic lines that somewhat covered the outskirts of the shoal, resulting in 5-10% variation. This trend shows that as seismic lines used in the calculations were located closer to the flanks of the shoal there was less variation in the volume calculation. This change in shoal coverage can be seen in figure 6 and figure 8. Figure 8 represents minimal flank coverage and figure 6 shows full seismic coverage of the shoal.

The data shows that at a line spacing of 720 meters (fig. 10), using only 5 of the 97 available seismic lines, the calculated volume was within 0.3% of the original calculated volume. To maintain full coverage of the shoal the next line spacing variation possible was 960 meters (fig. 12). To obtain this line spacing the center fix point could not be used but the calculated volume still only varied 0.3% from the original calculated volume. The shortcoming of this line spacing was in the isopach map created in Surfer™12. Due to the omission of the center fix point the isopach map did not accurately represent the thickest portion of the shoal and only showed a maximum thickness of 16 feet, while the isopach map created using 30-meter spacing showed a maximum thickness of 20 feet. Even though this line spacing can accurately calculate the volume of sand and depict the general shape of the shoal it was unable to accurately map the areas of the shoal with the greatest thicknesses. To maintain full coverage of the shoal, the next possible line spacing was 1440 meters (fig. 14). This line spacing yielded a 12.8% variation from the original calculated volume, indicating that 1440-meter line spacing was too large to meet our desired accuracy.

Reconnaissance level lines yielded a variation of 14.2% from the original calculated volume. The line spacing in the northwest-southeast oriented reconnaissance level lines was approximately 1000 meters and the two northeast-southwest lines were spaced approximately 600 meters apart (fig. 16). The 14.2% variation in volume calculated using the reconnaissance level data may be a result of data quality issues. This issue will be expanded on more in the conclusions below. Using only vibracore data a volume of 12,643,141 cubic yards of sand was calculated (fig. 18). This sand volume varied 17.3% from the original calculated volume.

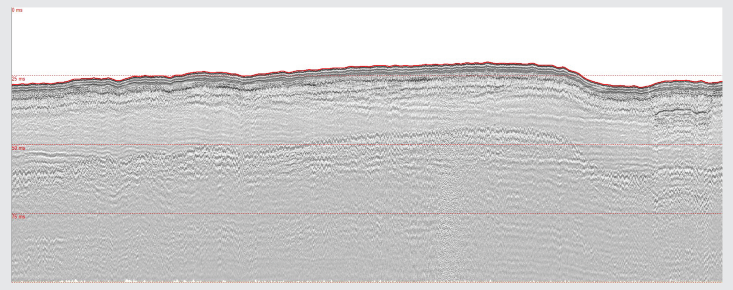
Figure 20: NJGWS seicmic line 733 collected in 2017 in the same location as CB&I Reconnaissance line NJ_085. Data collected with a HMS-620D Dual Source Boomer

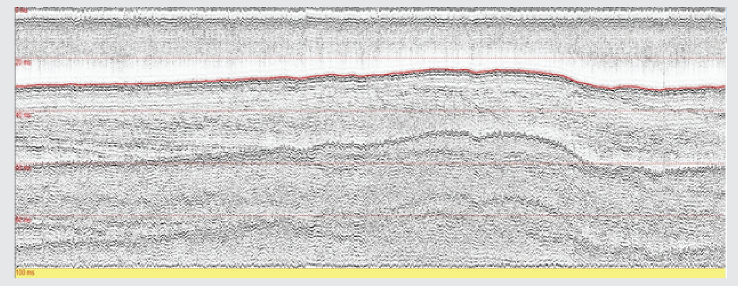
Figure 22: NJGWS line 645. This is an example of the data used in Kuhn et. al., 2016. CB&I Design Level line 335 was collected in the same location. Data collected in 2013 with an AA301 Boomer Plate.

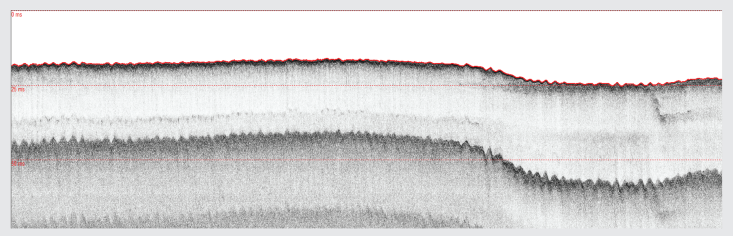
Figure 21: CB&I Reconnaissance line NJ_085

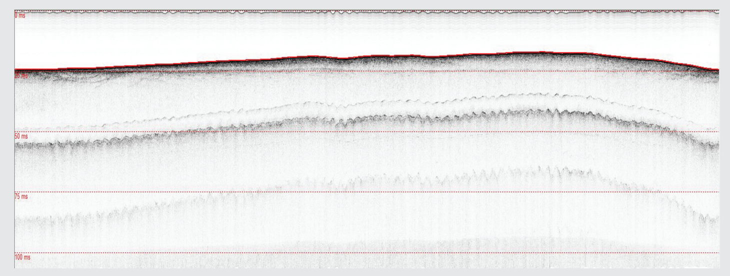
Figure 23: CB&I Design Level line NJ_DL_335

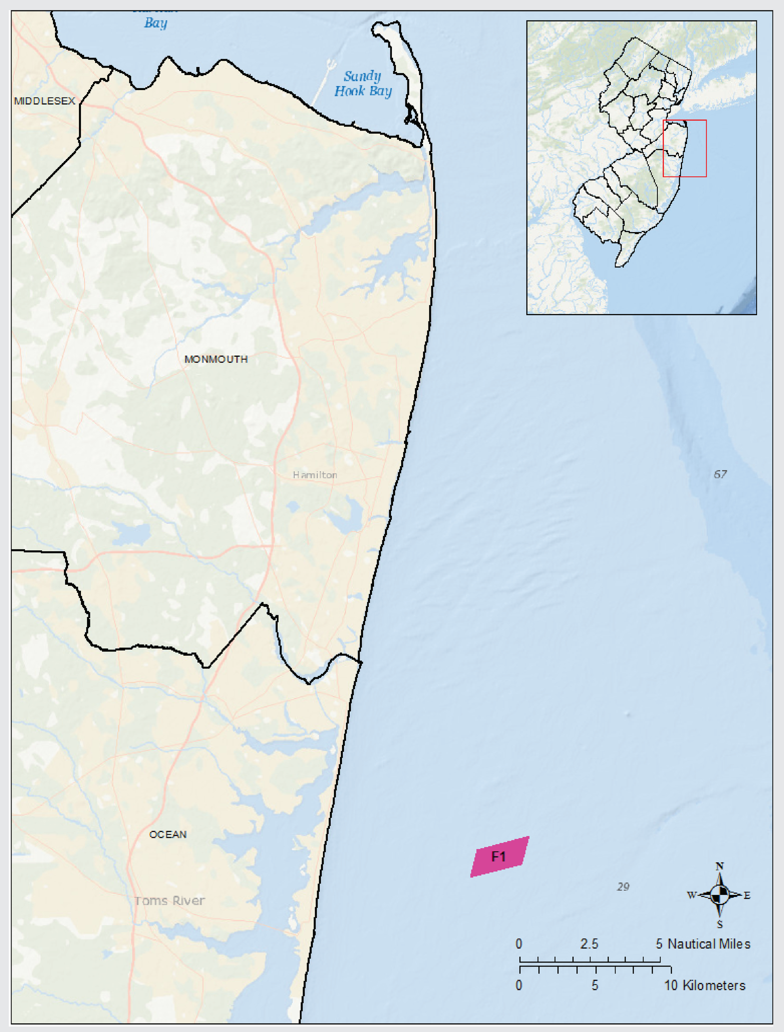
Figure 1: Location map of Area F1 offshore of New Jersey.


Photo of the M/V Atlantic Surveyor underway collecting geophysical data offshore New Jersey. Photo taken by Michelle Spencer (NJGWS).

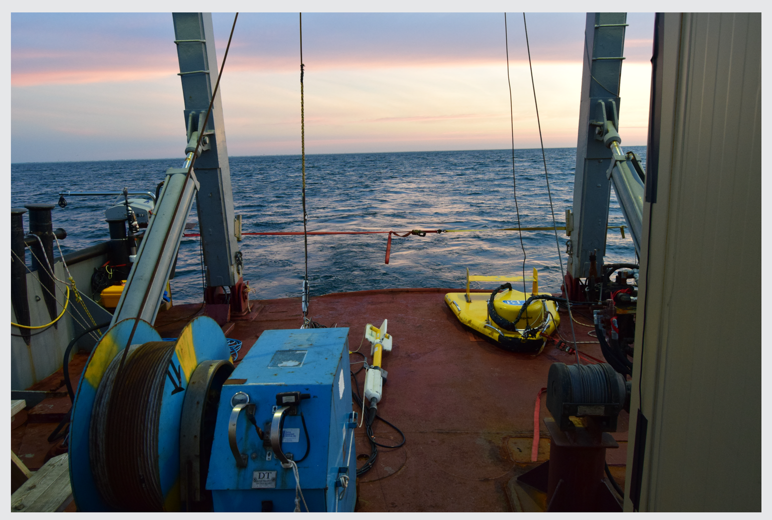
Photo of the geophyscal equipment used by CB&I for data collection offshore New Jersey. Photo taken by Michelle Spencer (NJGWS).

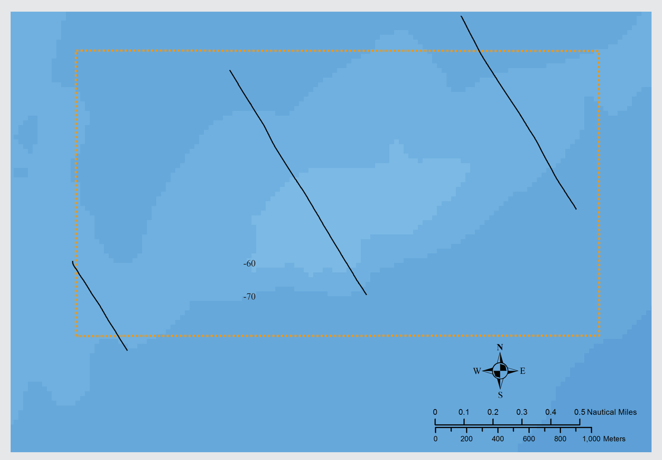
Figure 14: Locations of seismic lines at 1440-meter spacing. No vibracores were located on these lines. Orange dashes outline area of figure 15 below.

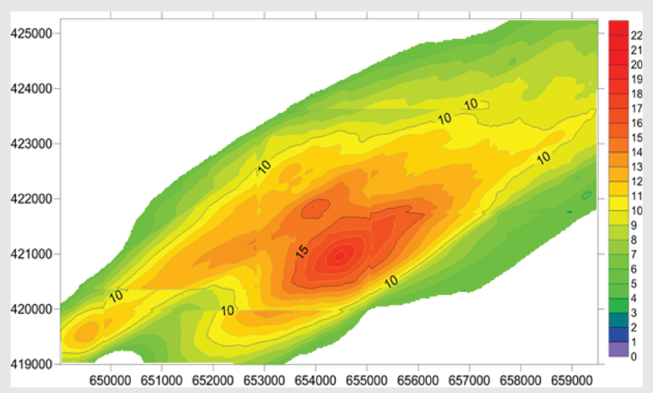
Figure 15: Isopach map created in Surfer™12 using data from seismic lines at 1440-meter spacing. Isopach was blanked at 5-foot contour.Thickness shown in feet. Coordinates in New Jersey State Plane Feet.

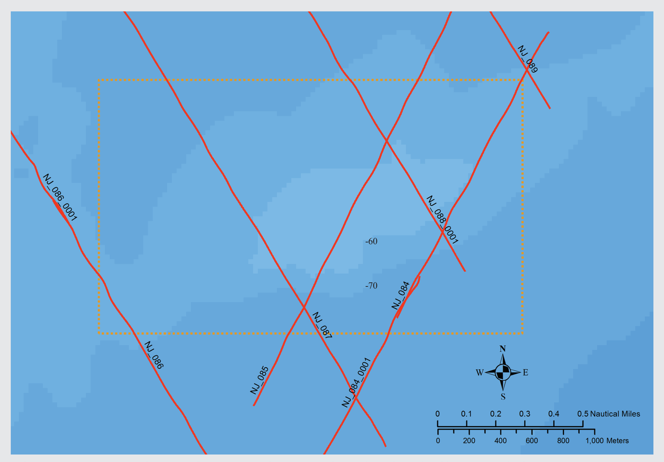
Figure 16: Locations of reconnaissance level seismic lines and the two reconnaissance level vibracores. Orange dashes outline area of figure 17 below.

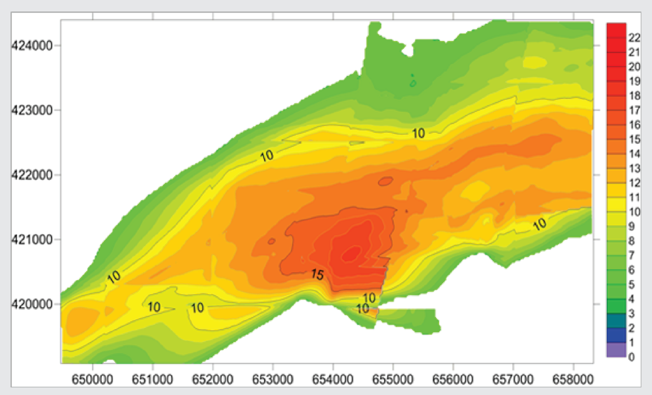
Figure 17: Isopach map created in Surfer™12 using data from reconnaissance level seismic lines. Isopach was blanked at 5-foot contour. Thickness shown in feet. Coordinates in New Jersey State Plane Feet.

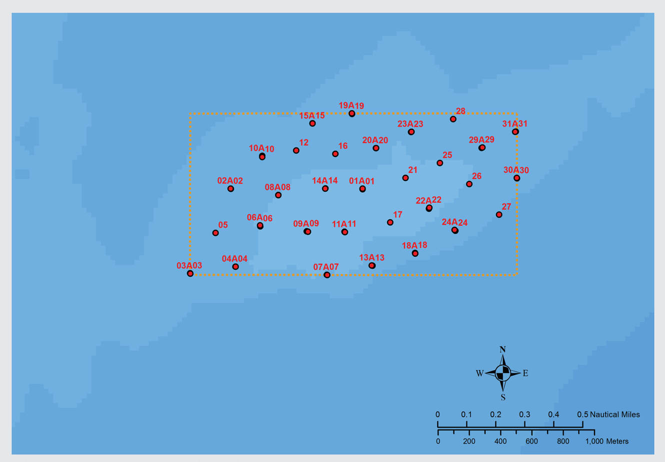
Figure 18: Locations of all design level vibracores. Orange dashes outline area of figure 19 below.

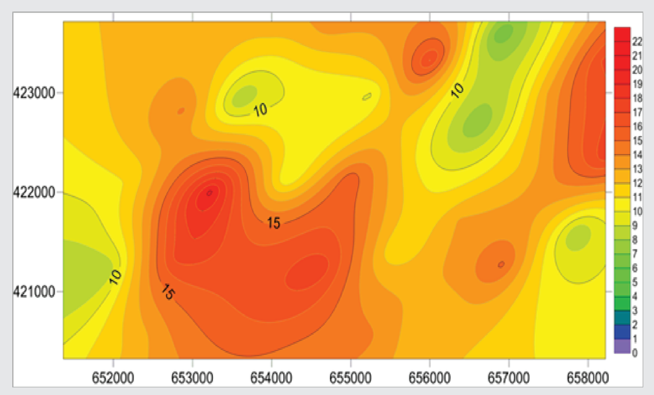
Figure 19: Isopach map created in Surfer™12 using data from design level vibracores. Thickness shown in feet. Coordinates in New Jersey State Plane Feet.

CONCLUSIONS

A sand volume of 15,286,148 cubic yards was calculated for area F1 using all the available data in this study. The preliminary sand resource assessment for northern Ocean County calculated a volume of 19,770,726 cubic yards (Kuhn et. al., 2016). These two analyses had a difference of approximately 4.5 million cubic yards. This discrepancy could have occurred due to factors such as differences in data quality affecting which reflector was traced as the base of sand, differences in the amount of vibracore and seismic data used for each assessment and differences in the type of seismic data that was collected and analyzed for each study. Both assessments show a very similar shoal shape and display realistic shoal features such as a steep southern shoal face and a more gradual sloping north face. They differ in that the preliminary analysis conducted by Kuhn et. al. shows larger thicknesses in the easterly portion of the shoal.

This project was completed using the data provided to the New Jersey Geological and Water Survey (NJGWS) by CB&I. Quality Assurance/ Quality Control was conducted by the NJGWS as deliverable F of the grant. In this QA/QC the reconnaissance data was classified as fair or poor quality. The design level data was classified as good to fair quality. The quality of the reconnaissance data is a potential source of error in the sand volume calculated with that data and likely affected the amount of variation from the original calculated volume. The data quality did not affect the line spacing comparisons because the analyzed sand thicknesses for each line remained the same for every calculation to ensure consistency. In 2017 NJGWS collected line 733 (fig. 20) in the same location of CB&I reconnaissance line NJ_085 (fig. 21) to use for data comparison purposes. NJGWS had previously collected seismic line 645 (fig. 22) in the exact same location as CB&I line NJ_DL_335 (fig. 23). In both instances the NJGWS shows higher resolution in the shallow subsurface and more visible features below the base of sand than the data collected by CB&I.

The NJGWS has several recommendations about how to more efficiently collect seismic and geologic data while still producing accurate sand volume calculations. The findings from this study show that design level line spacing of 720 meters can accurately estimate the sand volume of a shoal and will produce a reasonably accurate isopach map. NJGWS recommends to not solely collect seismic lines that are parallel to one another. There should be multiple tie lines, along the axis of the shoal, collected in a perpendicular orientation from the other seismic lines collected. Collecting seismic lines in multiple orientations helps to pull the data together and creates a more accurate representation of the shape and volume of the shoal in Surfer™12. The intersections of these tie lines are also beneficial locations to obtain core data, especially on the outskirts of the shoal where the core can show the exact depth of the base of sand. If a survey were to be conducted using these recommendations NJGWS believes that line spacing greater than 720 meters can be used while still maintaining accurate volume calculations. As shown by the 960-meter spacing, accurate sand volume estimates can be calculated at line spacings greater than 720 meters, however line placement plays a key role in isopach map accuracy. Using only vibracore data did not produce an accurate volume estimate; however, it does need to be recognized that the seismic data collected covers a larger area than the cores alone do. The isopach map that was created (fig. 19) did not accurately depict the shape and size of the shoal.

Based on the findings of this study, NJGWS makes a conservative recommendation for maximum design level seismic line spacing of 720 meters (0.39 nautical mile) contingent on 1) seismic coverage of full extent of the shoal, 2) a grid of perpendicular tie lines collected throughout the study area, and 3) vibracores located on intersections of the seismic lines and on the flanks of the shoal. Greater accuracy of sand volume calculations can be achieved with closer line spacings, however the line spacing of 30 meters collected by CB&I was found to be excessive and unnecessary.

References: Kuhn, M.E., Gagliano, M.P., Castelli, M.V., Uptegrove, J, 2016, Northern Ocean County offshore Sand Resource Area Synthesis and Assessment: "Sand-Resource Areas in Northern Ocean County, New Jersey".

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