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May 20, 2013

Mr. David Lederer
Remedial Project Manager
Office of Site Remediation and Restoration
EPA Region 1, Suite 100, OSRR 7-04
5 Post Office Square
Boston, MA 02176

Re: Addition of Blasting to the Final Determination, New Bedford South Terminal Project (New Bedford Marine Commerce Terminal (NBMCT Project)

Dear Mr. Lederer,

This letter is submitted in order to describe in detail the Massachusetts Clean Energy Center's (MassCEC's) petitioning of EPA to include blasting within an amendment to the Final Determination issued for the New Bedford South Terminal Project. The Commonwealth had previously outlined within a letter to EPA, dated October 4, 2012, that it intended to utilize blasting as a rock removal means of "last resort" (letter included as **Attachment A)**. However, since the date of that letter, the Commonwealth has acquired additional information on the subject and conducted detailed acoustic modeling to determine the environmental impact of blasting on marine resources (the final acoustic modeling report is included as **Attachment B)**. Through the process of completing the acoustic modeling, MassCEC has learned that the overall environmental impact from blasting is much smaller than initially estimated and, as outlined below, MassCEC has also determined that the use of blasting prior to the removal of the overburden will significantly minimize impacts to natural resources.

As EPA is aware, MassCEC recently solicited a Contractor for a portion of the construction of the South Terminal Project. Engagement with this Contractor has revealed that blasting is more likely to be required as a rock removal methodology than the Commonwealth had previously anticipated in its October 4, 2012 letter. This new information has prompted MassCEC to re-evaluate both the approach to blasting and its overall environmental impact. In response to this input from the Contractor, MassCEC has re-evaluated all of the acoustic modeling data that has been accumulated in support of this project. Through this process, MassCEC has come to the unanticipated but important conclusion that the environmental impacts of a blast implemented as a "last resort", when the overburden sediments have been removed exposing bedrock, are greater than the environmental impacts of a blast conducted when the overburden is left in place. Therefore, based on this new information (and as further outlined within this document), MassCEC respectfully petitions EPA to allow blasting prior to the removal of the overburden, rather than requiring that blasting be utilized only as a "last resort."

SDMS Doc ID 547255

Acoustic Modeling

As EPA is aware, the Commonwealth submitted a full Acoustic Modeling Report for its review on November 12, 2012. The full report is included as **Attachment B** to this document. The acoustic modeling was conducted by Jasco Applied Sciences of Nova Scotia, Canada, a respected consultant used by NMFS on similar projects. It was the Commonwealth's understanding in the fall of 2012 that blasting was anticipated to have a significant impact on the resource, and the modeling was intended to outline the impacts, such that engineering controls could be put in place, and/or further restrictions on the blasting could be designed and/or implemented. However, the results of the blasting indicated that the potential impacts were far less than the Commonwealth had originally anticipated. Below, please find as Insert 1 the Figures 20 and 21 from the Acoustic Modeling Report, which show the areal impacts of blasting utilizing bubble curtains:

Insert 1: Figures 20 and 21 from Acoustic Modeling Report – Peak Pressure (Left), Impulse Level Threshold (Right) – (Note Zoom in of Impact Area in Lower Right Corner)

Peak Pressure with Bubble Curtains:

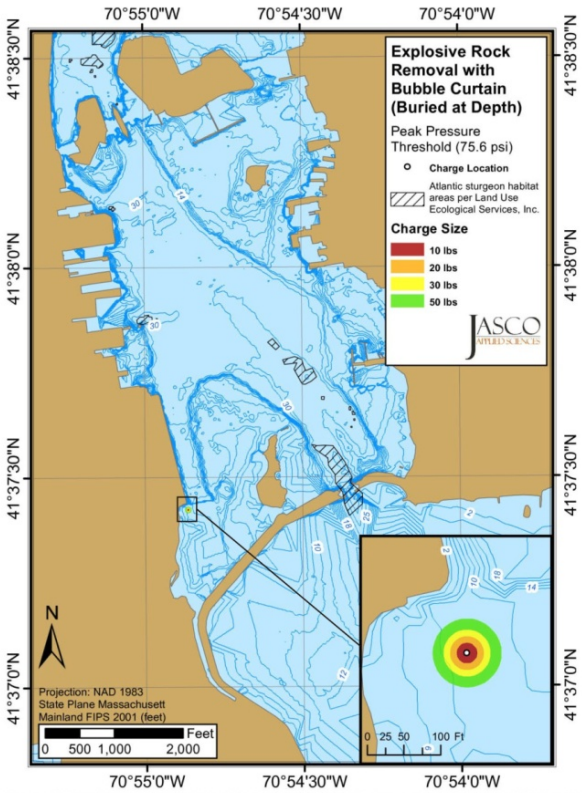


Figure 20. Explosive charge with bubble curtain at Site 2: Peak pressure threshold of 75.6 psi for explosive charges between 10 and 50 lbs. Blue contours indicate water depth in feet.

Impulse Level Threshold with Bubble Curtains:

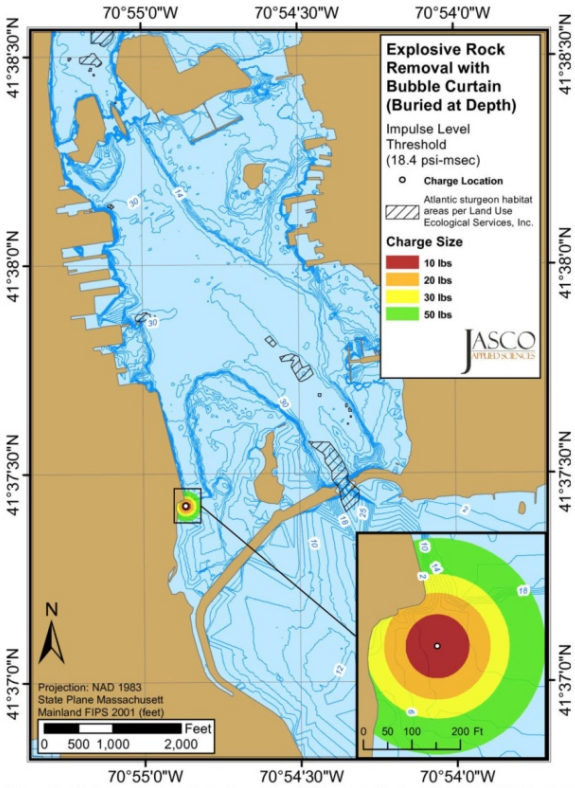


Figure 21. Explosive charge with bubble curtain at Site 2: Impulse level threshold of 18.4 psi·msec for explosive charges between 10 and 50 lbs. Blue contours indicate water depth in feet.

Figures 20 and 21 form the Commonwealth's Acoustic Modeling Report (**Insert 1** – above) demonstrate the acoustical impacts from a charge size of up to 50 pounds of explosives that are buried under a layer of overburden and rock. [It should be noted that initially, MassCEC's modeling sub-consultant had utilized 100 pounds of explosive charge for their models until MassCEC had suggested that the modelers reduce the charge size to 50 pounds, as requested by the US Army Corps of Engineers in order to minimize impact to the New Bedford Hurricane Barrier]. The two figures show the area that exceeds the Peak Pressure of 75.6 psi (left) and the Impulse Level Threshold of 18.4 psi-msec (right), versus distance from the blast location at various charge sizes up to 50 pounds. As is evident from the drawing, Impulse Level Threshold is the blast characteristic that has a larger impact area than Peak Pressure blast characteristic, and is therefore the controlling characteristic.

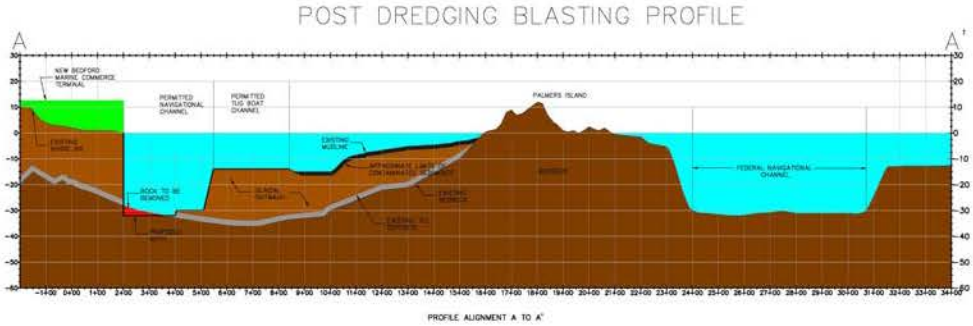
Factors Impacting Blast Results

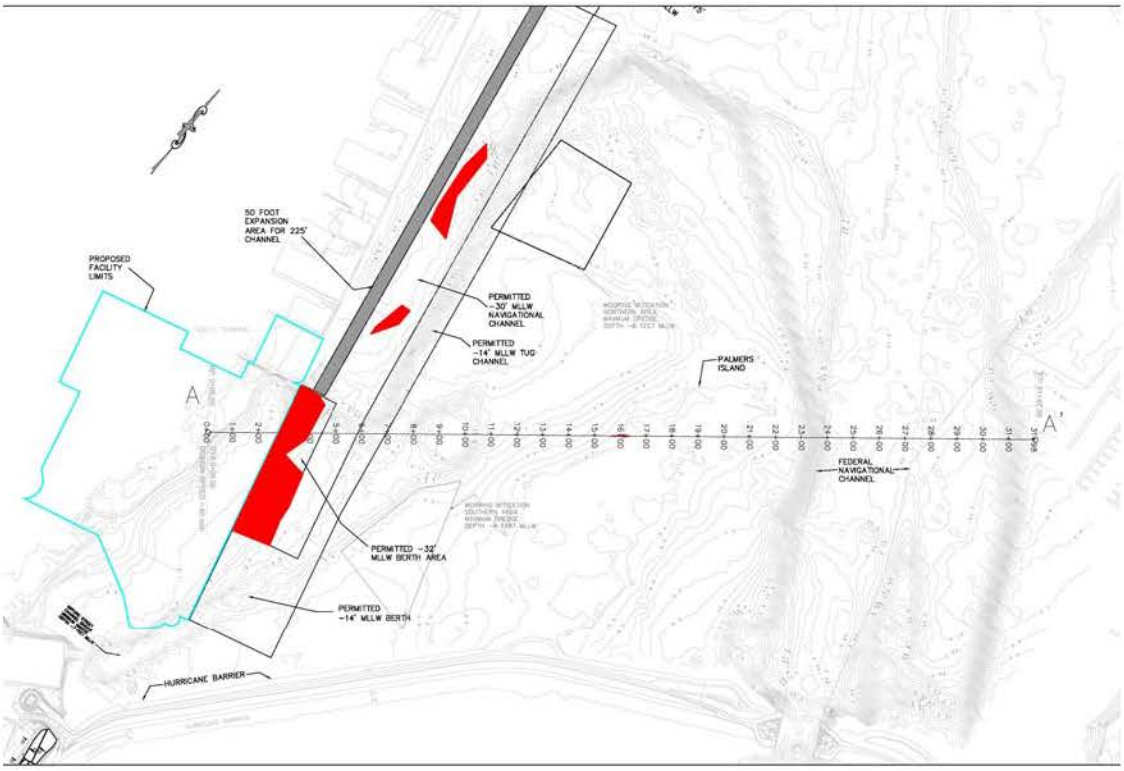
In order to better understand the overall impacts to resources from various blast condition scenarios, MassCEC re-analyzed all of the blasting model runs that were conducted by its acoustic modeling sub-consultant. Upon review, MassCEC found evidence that a blast with the overburden in place is less impactful than blasting as a "last resort" due to the following factors:

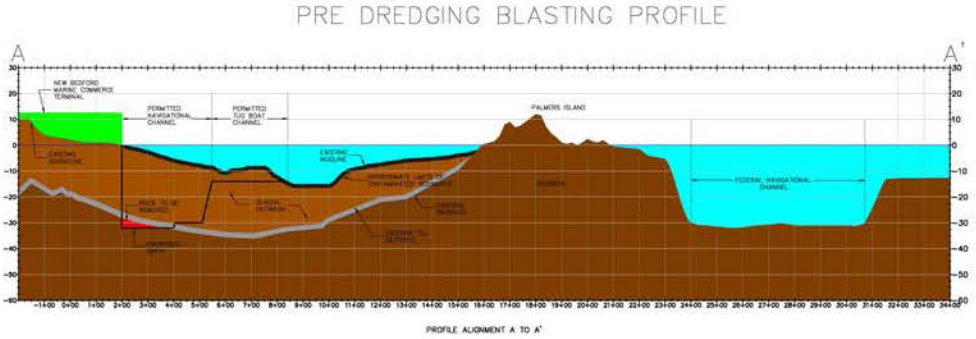
- The overburden material acts to absorb a significant portion of the blast energy; and
- Project sequencing would result in blasting at a more sensitive time of year (spring spawning season).

The mechanics of the two scenarios are outlined in more detail within **Insert 2** on the following page:

Insert 2: Mechanics of "In Water" (Post-Dredging) Blasting Scenario and Blasting Prior to Overburden Removal (Pre-Dredging) Scenario







Insert 2 shows the outline of the facility superimposed over existing bathymetry. A cross-section is outlined through one of the areas requiring blasting and the cross-section is shown for two scenarios: blasting prior to the removal of the majority of the overburden and blasting only as a "last resort", after removal of all of the overburden. *Importantly, please note that contaminated material would be dredged and disposed of into CAD Cell #3 prior to any blasting in either scenario and in no case would contaminated material be left in place during blasting.* Rock is noted on the plan and cross-sections in red.

The "Post-Dredging Blasting Profile" (top of previous page) reflects a use of blasting as a "last resort". Under this scenario the overburden, which would otherwise absorb the energy of the blast, has been removed.

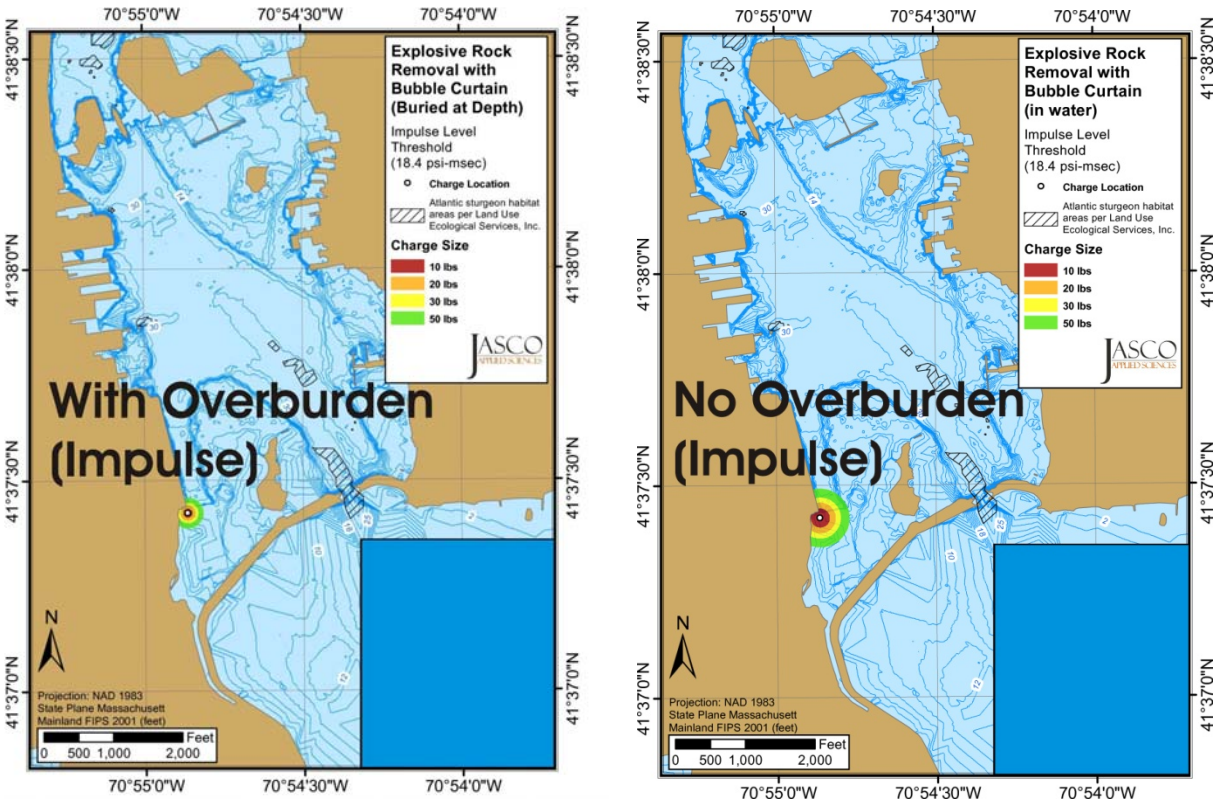
In the "Pre-Dredging Blasting Profile" (bottom of page), the overburden (absent the contaminated dredge material that has already been removed) is still in place. As a result, much of the blast energy is absorbed by the overburden and the resource impact is reduced.

Blasting with Overburden vs. Blasting without Overburden

In order to assess the condition where blasting would occur with the overburden removed, MassCEC re-analyzed the modeling data that represented the "In Water" blast condition, whereby a blast conducted at the bottom of the water column was modeled. In this scenario, the blast is assumed to take place on the bottom of the harbor after the overburden and mechanical rock removal has been attempted (top cross section in **Insert 2**). The two figures below in **Insert 3** show the area that exceeds the Impulse Level Threshold of 18.4 psi-msec at various charge sizes up to 50 pounds for both "Buried at Depth" ("With Overburden") and "In Water" ("No Overburden") scenarios, in order to compare the impact of the two side-by-side.

Comparison of these two figures in **Insert 3**, demonstrates that the overall acoustical impact of blasting with "No Overburden" (right) is noticeably larger than "With Overburden" in place (left). For Impulse Level Threshold, the radial distance between the detonation point and the outer rim of the impact for the 50 pound charge level with "No Overburden" is approximately 390 feet. The radial distance between the detonation point and the outer rim of the impact for the 50 pound charge level "With Overburden" is approximately 210 feet.

Insert 3: Comparison of "Buried at Depth" (Left) and "In Water" (Right) Modeling Results



As the model results shown above indicate, compared to the "Buried at Depth" ("With Overburden") modeling scenario (which would have a 100% environmental impact within a 210 foot radius), the "In Water" ("No Overburden") scenario has a 345% ($390^2/210^2$) areal impact by comparison. Please note that this larger acoustical impact would be compounded further by the noise and turbidity impacts of extended mechanical rock removal efforts that would be required in a "last resort" scenario before blasting is attempted.

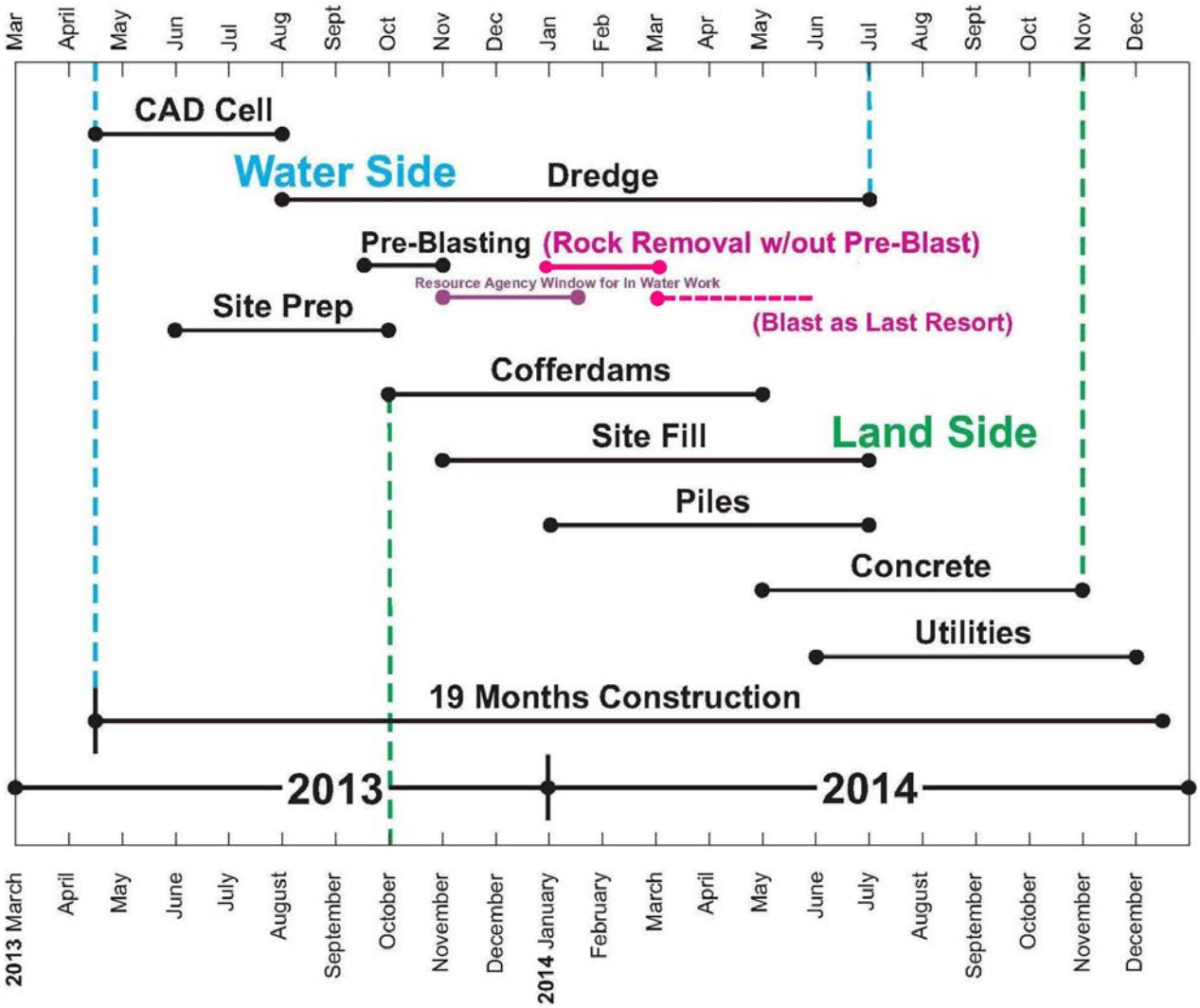
Blasting Time of Year Issues

In addition, the implementation of blasting as a "last resort" also may force MassCEC to initiate blasting at a more unfavorable time of year than if blasting were to occur prior to the exposure of bedrock. As shown in the updated schedule obtained from the selected contractor, the earliest blasting as a "last resort" scenario could take place is March of 2014. We anticipate non-blasting rock removal efforts would begin in January of 2014 and take several months, with blasting as a "last resort" occurring throughout the spring season of 2014. However, pre-blasting with the overburden in place would occur in mid September 2013. Again, please note that the "Top of Dredge" layer will be completely removed prior to any blasting. Some of the "Intermediate Dredge Layer" may also be removed, leaving between 5-7 and 15-20 feet of overburden in place prior to blasting.

The following **Insert 4** outlines MassCEC's anticipated schedule, and shows how the two rock removal scenarios impact the schedule of various activities:

- "Pre-Blasting" represents blasting with the overburden in place;
- "Rock Removal w/out Pre-Blast" represents mechanical efforts to remove rock, and
- "Blast as Last Resort" represents a time period where blasting is initiated after mechanical rock removal has proven inadequate.

Insert 4: MassCEC's Anticipated Schedule



Thus, due to the timing of project construction, and the uncertainty with regard to the use of blasting as a "last resort", the "rock removal without pre-blast" would begin in the early winter, and blasting as a "last resort" would likely occur in early spring to the early summer, in the middle of the spawning season for many types of piscine resources. However, blasting prior to

the removal of overburden, or "pre-blasting", would likely occur in the late fall, within an approximately one month window beginning on September 15th. As a result, blasting prior to the removal of the overburden is a less impactful activity.

Blasting as a "last resort" will also impact MassCEC's critical path for its project. A review of the time frame anticipated for blasting-as-a-last-resort indicates that because blasting must be performed prior to sheet pile installation, and sheet pile installation associated with the bulkhead construction is a long time-frame item for which there is no short-cut or work around available, blasting as a last resort will delay MassCEC's target completion date by up to six months.

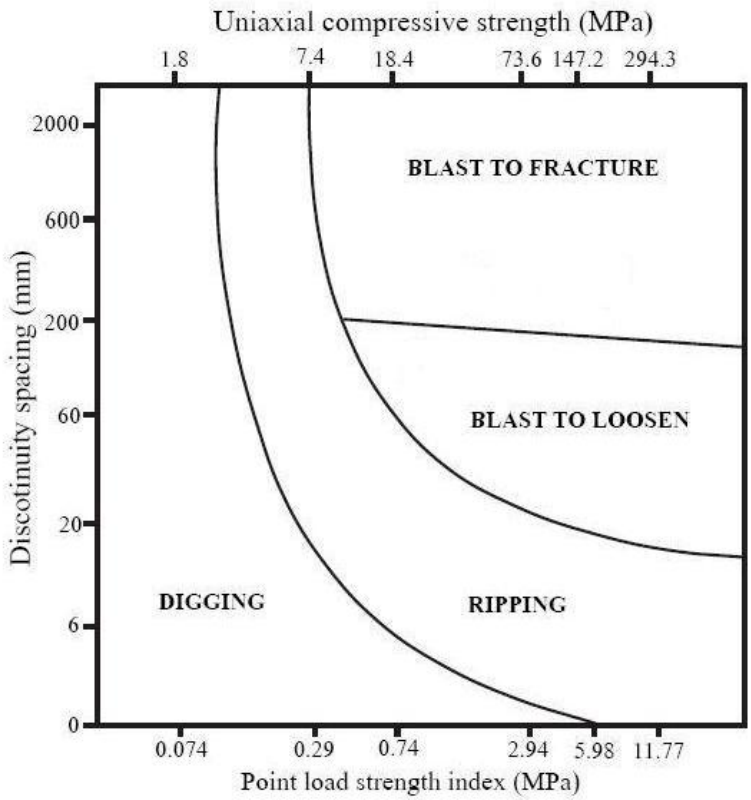
Please also note that due to the timing and sequencing requirements of the construction process, MassCEC has little flexibility to allow its contractor to delay implementation of the blasting in the "pre-blasting" scenario. The necessary sequencing of work requires that the CAD Cell be constructed and the contaminated surface layer in the blast zone be removed (and placed into the CAD Cell) prior to blasting. These activities will be completed by approximately the middle of September of 2013, at which time the pre-blasting could commence. The project cannot afford to have the Contractor wait until November to commence pre-blasting, as this delay in the sequencing would have the effect of delaying the start of the installation of the sheet pile wall by several months. The installation of the sheet pile wall is the most critical time element within the construction sequence, and a delay of several months would cause MassCEC to miss the end-of-construction deadline for the first user of the terminal.

Necessity and Likelihood of Blasting

Although MassCEC determined that blasting in a "last resort" scenario would be more impactful than blasting prior to the removal of the overburden, it was not clear to MassCEC whether the same quantity of blasting would be required in a "last resort" scenario vs. a scenario in which the overburden were left in place. Therefore, MassCEC researched the likelihood of the need for blasting in either scenario, as outlined below.

MassCEC met with Cashman-Weeks NB and discussed the likelihood of blasting in association with the South Terminal Project. Cashman-Weeks NB's experience is significant in this area. Cashman-Weeks NB indicated that it is very confident that blasting will be required based on the existing rock data and past experience with similar jobs. MassCEC asked Cashman-Weeks NB to provide evidence that blasting would be required (as the Commonwealth had previously believed that blasting may not be required as stipulated within its October 4, 2012 letter, and would likely be utilized only as a "last resort"), and the Contractor forwarded the following figure which outlines an "excavatability classification system" generated within following paper: "Franklin J.A,. Broch E, Walton G (1971). Logging the mechanical character of rock. Transactions of the Institute. Min. Metallurgy. 80: A1-9." (see **Attachment C** for the original paper). Please note that the following figure has (since first publication) been refined to include information quantifying values on the main axes in order to facilitate the use of laboratory data when utilizing the table.

Insert 5: Excavatability Classification System From Franklin et a. (1971)



Assesment of rock masses with reference to excavatability classification system of Franklin et al. (1971).

The Franklin, et Al. system utilizes either the Uniaxial Compressive Strength or the Point Load Strength Index and the Discontinuity Spacing (i.e. spacing of fractures) to determine the likelihood of the need for blasting. In layman's terms, the need for blasting relates directly to how hard the rock is, and how highly fractured the rock. The data collected to date regarding the compressive strength of rock at the site is attached as **Attachment D** and is shown below:

Table 1: Summary of Rock Core Strength Testing

Rock Core	Compressive Strength (psi)	Compressive Strength (MPa)	Point Load Strength (psi)	Point Load Strength (MPa)
A-2010-B2/C1	N/A	N/A	403	2.8
A-2010-B3/C1	15,510	106.9	N/A	N/A
A-2010-B4/C2	12,926	87.1	N/A	N/A
A-2010-B9/C1	14,656	101.1	N/A	N/A
A-2010-B9A/C1	15,159	104.5	N/A	N/A
A-2011-B11/C1	7,575	52.2	N/A	N/A
A-2011-B18/C1	N/A	N/A	1025	7.1
A-2011-B19/C1	15,429	106.4	N/A	N/A
A-2011-B31/C2	36,367	250.7	N/A	N/A
A-2011-B32/C1	11,542	79.6	N/A	N/A

Based on the schematic shown in **Insert 5**, rock with compressive strengths greater than approximately 73.6 MPa, and/or Point Load Strength greater than 2.94 MPa will require blasting either to loosen the rock to allow mechanical removal and/or to fracture the rock to allow subsequent mechanical removal if the "Discontinuity Spacing" or fracture spacing is greater than 20 mm. Please note that 20 mm is less than one inch in length. Photographs of the rock cores are included in **Attachment E** to this document, which indicate that most of the fracture spacing within the cores collected from areas where rock blasting may be required indicate greater than 1-inch spacing for the majority of the cores. As a result, Cashman-Weeks NB has concluded that the rock removal required for this project will ultimately require blasting over a fairly large percentage of the in-situ rock removal area.

It is also Cashman-Weeks NB's experience that it is unlikely (as the Commonwealth had previously presumed within its October 4, 2012 letter) that some of the rock may be removed mechanically, leaving only a little to be blasted. Cashman-Weeks NB instead believes, based on their analysis of the rock composition, that, since rock quality and type does not vary significantly over the footprint of the work, rock will either be able to be removed mechanically or not (i.e. difficult to remove rock will not suddenly become easy to remove in some locations). Additionally, partial removal of rock will not eliminate the need for blasting (for example, if four feet of rock must be removed, and three feet of rock can be removed mechanically, blasting will still be required for the remaining foot of rock).

As a result, the following estimate has been produced (based on the total area estimated to require blasting) as to the percent likelihood that the blasting will be required as follows:

Table 2: Likelihood of Blasting Based on Percent of Total Area Requiring Blasting

Percent of Total Area Estimated to Require Blasting	Estimated Chance that Blasting Will Be Required
50%	90%
18.8%	80%
21.2%	50%

Relative Environmental Impact

Although the modeling conducted by MassCEC reveals that the environmental impacts of a blast implemented as a "last resort" appear to be greater than the environmental impacts of a blast conducted prior to removal of overburden and the exposure of bedrock, and the information generated by Cashman-Weeks NB has indicated that blasting is far more likely than previously estimated, MassCEC required a quantitative measure to be able to determine the least environmentally impactful scenario.

In order to provide a method to quantify the relative environmental impacts, MassCEC proposes the following analysis:

- MassCEC proposes a "Total Relative Environmental Impact" variable that represents the comparable impact of two different scenarios. The variable consists of the percent of area to be blasted times the chance that blasting will be necessary, times a relative environmental impact factor, as follows:

Percent of Area Requiring Blasting	**X**	**Chance of Blasting**	**X**	**Relative Environmental Impact**	**=**	**Total Relative Environmental Impact**

Where:

Percent of Area Requiring Blasting is the portion of the total area that may require blasting calculated by subtracting the known rock elevation and the target dredge elevation.

Chance of Blasting is the estimate based on the rock type, quality, and thickness that blasting will be required.

Relative Environmental Impact Factor is a factor that gauges the proportional increase or decrease per area blasted in the probable environmental impact associated with blasting based on the measured distance of the impact Impulse Threshold Level, compared to a blasting scenario that leaves the overburden in place.

Total Relative Environmental Impact is the relative environmental impact as compared to a blasting scenario that leaves the overburden in place.

These Total Relative Environmental Impact values has been calculated based on the following methodology:

- The Percent of Area Requiring Blasting and the Chance of Blasting were gathered based on advice and recommendations outlined by Cashman-Weeks NB, and as shown within **Table 2**.
- The Relative Environmental Impact Factor is based on the relative difference in impact associated with acoustical impacts (as quantified by the Impulse Threshold Level) between a scenario in which the overburden is left in place prior to blasting and a scenario in which bedrock is exposed and blasting is utilized as a "last resort". The values utilized for this factor are 1.00 (representing 100% environmental impact) for when the overburden is left in place and 3.45 (representing 345% areal environmental impact) when bedrock is exposed and blasting is utilized as a "last resort".
- The Total Relative Environmental Impact is the sum of the Subtotal of Relative Environmental Impacts for the different areas of blasting under consideration. The higher number represents a larger relative environmental impact, and is calculated as shown in **Table 3** as follows:

Table 3: Estimate of Relative Environmental Impact In Pre-Blast vs. Blast as "Last Resort" Scenarios

Scenario	Blast Prior to Exposure of Bedrock	Blast as "Last Resort"		
Percent of Area Requiring Blasting	100%	50%	18.8%	21.2%
Chance of Blasting	100%	90%	80%	50%
Relative Environmental Impact Factor	1.00	3.45	3.45	3.45
Subtotal of Relative Environmental Impact	1.00	1.55	0.52	0.37
Total Relative Environmental Impact (sum of all subtotal items)	1.00	2.44		

The result of MassCEC's analysis is that blasting as a "Last Resort" is 144% more impactful than blasting prior to the exposure of bedrock.

Again, please note that this larger impact would be compounded by the noise and turbidity impacts of mechanical rock removal efforts (not included in the Total Relative Environmental Impact calculation) that will be required in a "last resort" scenario before blasting is even attempted. Although the noise and turbidity impacts of mechanical rock removal have previously been determined to be acceptable by EPA, if blasting is likely in either scenario, mechanical rock removal creates additional cumulative noise.

Based on this analysis and the information presented previously, we conclude that, even when considering the potential that blasting may not be required in some areas, blasting prior to the removal of the overburden will be the least impactful alternative.

Therefore, MassCEC petitions that EPA allow the use of blasting prior to the removal of the overburden in order to minimize impacts to natural resources.

Blasting Protections To Be Put In Place

MassCEC understands that the EPA is concerned with the potential impact to fish communities due to blasting, primarily as a result of issues that were generated during blasting that was overseen by the USACE during 2007. MassCEC has reviewed a paper forwarded by EPA entitled "AFTER ACTION REPORT ON THE FISH KILLS RESULTING FROM BLASTING IN SUPPORT OF ROCK REMOVAL FROM THE FEDERAL NAVIGATION PROJECT -BOSTON HARBOR, MASSACHUSETTS- (FALL 2007), by the USACE, dated June 2008" (included as **Attachment F**).

MassCEC is aware that communication problems between the fish observers and the contractors appear to have been a large source of the issues that resulted in large quantities of fish being killed within New Bedford Harbor during this project. MassCEC has discussed this issue with Cashman-Weeks NB, and the Contractor has prepared the following operation and communication plan (see **Attachment G**) that is intended to minimize the chance that such a miscommunication will take place in association with the South Terminal Project.

Prior to blasting, MassCEC proposes to isolate the blast areas in a similar method as has previously been successful in association with the Fish Deterrent System. It is MassCEC's understanding that flatfish will not be as high a concern as during the conventional implementation of the Fish Deterrent System; therefore fish weirs will not be installed as part of this effort. Silt curtains will be installed to prevent fish from entering the potential blast areas. The acoustic modeling conducted to date clearly indicates the areas that have the greatest likelihood of being affected by the blasting (i.e. the radius as noted previously around each blast site), and therefore will also be the areas within which fish exclusion efforts will be focused. Prior to the initiation of blasting, a fish inspection (similar to those associated with the Fish Deterrent System) will be undertaken to determine if fish are present in the blast area. MassCEC will perform the fish inspection in compliance with Fish Deterrent System protocols. If necessary, "fish scaring" or "fish startling" will be used to clear the area of fish. The historic effectiveness of this methodology indicates that multiple "fish startling/scaring" efforts will not be

necessary. Subsequent to the clearing of the area, drilling and preparation of the area for blasting will begin.

Due to the human and public safety risk involved with placing explosives, the Contractor is constrained by a time limit with regard to how long the holes may stay open with explosives in place, prior to blasting. In order to make the most efficient use of this time, the Contractor proposes to work diligently to drill and install explosives in the shortest time possible, in order to leave sufficient time once the blast is prepared to monitoring for the presence of schools of fish. In addition, the Contractor has outlined its communication plans associated with the work to demonstrate how clear lines of communication will be maintained. The details of the Contractor's plan are included within **Attachment G**.

As outlined within MassCEC's specification section 02900 – BLASTING, a dedicated marine observer will be on hand to ensure that a concerted effort is being undertaken to inspect for the presence of schools of fish. This extra time will also allow for "fish scaring" should fish be observed prior to the actuation of any blasting. However, please note that worker safety will take precedence over inspection and scaring operations if necessary in the blasting area.

MassCEC believes that these measures will ensure that the impacts observed in Boston Harbor are not repeated on the South Terminal Project.

MassCEC would also like to repeat that Section 02900, Part 3.9.2.1, Subpart 8 of the specifications for the New Bedford Marine Commerce Terminal require the use of both silt curtains and bubble curtains to enclose blasting areas.

Please note that Cashman-Weeks NB has informed MassCEC that they will need to know which method will be utilized by June 1, 2013 in order to be able to prepare for the logistical, administrative and permitting aspects of a blasting program, if approved.

Finally, USEPA has requested clarification regarding the prior ARARs analysis performed by the Commonwealth regarding the implementation of blasting. It is MassCEC's understanding that the Commonwealth considered the implementation of blasting within its June 18, 2012 ARAR's letter contained within Appendix D to the Final Determination (blasting is noted on page 2 of that letter within the list of potential impacts).

MassCEC sincerely appreciates your consideration of this very important matter. If you have any questions related to this proposed modification to the Final Determination, please do not hesitate to contact me at 617-315-9330.

Sincerely,

Bill White

Bill White
Director, Offshore Wind Sector Development

ATTACHMENT A

The Commonwealth of Massachusetts
Executive Office of Energy and Environmental Affairs
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Boston, MA 02114

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October 4, 2012

Elaine Stanley
U.S. Environmental Protection Agency
New England Region
5 Post Office Square, Suite 100
Boston, MA 02190

Re: Response to National Oceanic and Atmospheric Administration – National Marine Fisheries Service, Northeast Region Comments on the Draft Determination for the Proposed South Terminal Project, New Bedford, Massachusetts

Dear Ms. Stanley:

Following an August 21, 2012 comment letter to EPA from the National Marine Fisheries Service (NMFS) on the Draft Determination for South Terminal in New Bedford, MA, the Commonwealth convened our team, including our fisheries experts at the Massachusetts Division of Marine Fisheries and project engineers, to meet with NOAA's Regional Administrator John Bullard and NMFS staff to provide a full briefing of the project and detail the project's significant environmental benefits to New Bedford Harbor. At the meeting, we explained the extensive mitigation that the Commonwealth has committed to conduct in the areas of winter flounder habitat, salt marsh restoration, and shellfish reseeding. Additionally, we had the opportunity to clarify and address NMFS concerns regarding impact to fisheries. This letter serves to summarize the Commonwealth's conversation with NMFS and detail the collective approach that has been devised that allows the project to be completed in a manner that protects the potentially impacted resources while maintaining the critical project elements to meet the intended project purpose.

At the meetings, which took place at the Massachusetts Executive Office of Energy and Environmental Affairs on September 21 and 28, 2012, we discussed three main points relative to impacts on fishery resources regarding the South Terminal project: mitigating potential impacts to the endangered Atlantic sturgeon, designing engineering controls to protect winter flounder and anadromous fish species, and refining the Commonwealth's proposed shellfish mitigation plan.

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Atlantic Sturgeon

Atlantic sturgeon (*Acipenser oxyrinchus*) is a migratory anadromous species, migrating from the open ocean to coastal rivers to spawn in the spring. All coastal waters along the East Coast, including Buzzards Bay and New Bedford Harbor, are *potential* habitat for Atlantic sturgeon. However, according to NMFS, Atlantic sturgeon are only currently present in approximately 32 rivers from from St. Croix, ME to the Saint Johns River, FL. In Massachusetts, Atlantic sturgeon have been observed along the coast, but have not been observed spawning in the Taunton River (the closest historical spawning river to New Bedford Harbor) for over 15 years (NMFS letter to EPA dated 6-19-12). Additionally, DMF has never spotted the species at or near New Bedford Harbor. In fact, according to NOAA's Distribution and Abundance of Fishes and Invertebrates in Mid-Atlantic estuaries, Atlantic sturgeon have not been observed in Buzzards Bay, and furthermore are listed as rare in Buzzard's Bay under the basis of "reasonable inference" (Stone et al. 1994).

DMF assesses the potential for spawning and forage habitat in all waterbodies for species of concern with respect to impacts from construction projects, including Atlantic sturgeon (Evans et al. 2011). However, New Bedford Harbor has several important characteristics that make it an unlikely environment for Atlantic sturgeon including: a severely restricted entrance (the hurricane barrier) that is constantly monitored, a large amount of vessel traffic, a large seafaring population surrounding the harbor, an extensive Superfund dredging project, frequent navigational dredging conducted under EPA authority, and an anadromous fish restoration project in the Achushnet River. And despite the vulnerability of Atlantic sturgeon to vessel strikes and the relative ease with which these large fish are seen compared to other fish, there have been no reported incidents of vessel strikes to Atlantic sturgeon near or within the New Bedford Harbor.

Furthermore, no Atlantic sturgeon were caught in monthly surveys conducted in New Bedford Harbor for Dredge Material Management Planning (DMMP, Normandeau 1999). Therefore, DMF concluded that Atlantic sturgeon were not present in New Bedford Harbor. Accordingly, we do not make recommendations pertaining to Atlantic sturgeon during our environmental review of the large number of federal and state projects that occur in the harbor. However, we recognize the importance of the Endangered Species Act (ESA) listing and offer the following information and mitigation strategies based on guidance provided by NMFS.

As background, the project calls for the installation of a 1,000 lineal foot coffer-dam style bulkhead with an overhanging pile-supported concrete deck along the quay-side. In order to do this, the Commonwealth will be installing flat sheet piles (to create the coffer-dam structure), z-shaped sheet piles (for the southern return wall) and pipe piles (to support the overhanging concrete deck). The sheet pile installation and pipe pile installation

information can be divided into three categories including cofferdam, return wall area, and concrete decking.

For the cofferdam, the Commonwealth will be installing approximately 3,034 thin flat steel sheets that are approximately 19" long and approximately 0.5" thick. These will be installed to form the cellular structure of the cofferdams.

For the return wall area, the Commonwealth will be driving approximately 175 z-shaped steel sheet piles that are approximately 30" long and approximately 3/8" thick. These sheets will be installed along the southern end of the facility in association with the return wall.

For support of the concrete decking, the Commonwealth will be installing three different types of pipe pilings. The first set will include 65 pipe piles that are 24" diameter and have 5/8" wall thickness. These will be installed after the cofferdams are installed and will be installed outside of the cofferdams. However, these pilings will be installed by drilling a "rock socket" in place, placing the piling in the hole, and then grouting it in place. This first set of pilings will not require driving and will be installed in accordance with the "drill and pin to ledge" criteria that NMFS has already stated would be acceptable for installation at all times of the year.

The second set will include 22 pipe piles that are 30" diameter and have 3/4" wall thickness. These will be installed after the cofferdams are installed and will be installed outside of the cofferdams. These pilings will also be installed by drilling a "rock socket" in place, placing the piling in the hole, and then grouting it in place. Similar to the first set, the second set of pilings will not require driving and will be installed in accordance with the "drill and pin to ledge" criteria that NMFS has already stated would be acceptable for installation at all times of the year.

The third set will include 94 pipe piles that are 30" diameter and have ¾" wall thickness. These will be installed after the cofferdams are installed and filled, and will be installed inside of the footprint of the completed cofferdams. These pilings will be vibrated and/or driven, however, because the cofferdams will be completed and filled with earth by the time these piles are installed, the pilings will be driven into earth above the water surface (i.e. – dry land), and as an upland activity this work will not contribute to noise impacts to fisheries resources.

The project also requires the removal of a relatively small quantity of rock from some of the deeper dredge areas near the quay-side portion of the future vessel berth area.

NMFS has expressed concern that acoustic and vibrational energy from the installation of the piles and the bedrock removal methods may adversely impact ESA listed Atlantic

sturgeon within their normal migratory ranges. NMFS offered the following guidance to promote mitigation of potential impacts to that species: install piles between November 15th and March 15th; or institute engineering controls to ameliorate vibrational energy in the water column if pile driving must occur outside the recommended time frame. Additionally, NMFS provided additional specifications regarding noise impacts to Sturgeon from vibration-causing activities during a teleconference held on October 2, 2012 as follows:

- Threshold for onset of injury – peak measurement: Peak SPL of any strike that exceeds 206 dB re: 1uPa.
- Threshold for onset of injury – cumulative measurement: cumulative SEL (cSEL), accumulated over all pile strikes, exceeds 187 dB re 1 uPa•s. Note: for vibratory hammer pile advancement, assessment of cSEL may be completed using one of two methods: either equating the number of vibratory periods to the number of pile strikes or using the duration of vibration in the calculation.
- Threshold for behavioral effects: 150 dB_{RMS}

The construction methods anticipated for the various activities noted above include:

- Sheet pile driving activities utilizing a vibratory pile driving system (pipe piles are not currently anticipated to contribute to noise impacts, as discussed above);
- Drilling activities associated with "rock-socketing" of pipe piles drilled into rock;
- Mechanical fracturing of shallow rock patches within the dredge footprint where rock may be encountered (either utilizing a bucket dredge , a "hoe-ram", or hydraulic dredge capable of removing rock); and
- Drilling of small holes into small patches of shallow rock outcroppings in the dredge areas and the injection of expanding grout into those holes for the fracturing of rock so that it can be dredged by traditional means.

Because the critical path nature of the project timeline anticipates the potential for work during the March to November timeframe, the Commonwealth proposes to implement the following engineering controls to mitigate the potential for the noted construction activities impacting the resource:

- "Rock-socketing", or drilling the pipe piles into bedrock;
- Limiting the installation methods to the use of vibratory hammers for the installation of piles to the extent practicable;
- If impact hammers are necessary, attempt to, if practicable, limit the use to one hammer and no more that 50 piles installed per day.

Additionally, prior to the start of construction, the Commonwealth will conduct acoustical modeling of the potential noise-generating pile installation activities noted

above to demonstrate that in-water noise levels will not exceed thresholds for physiological impacts or mortality (as noted above) at the zone of passage. Should modeling indicate that acoustical noise levels will exceed the levels indicated above, then additional engineering controls in the form of noise attenuating bubble curtains between the work area and the zone of passage would be employed for work that would occur outside the November to March timeframe.

On the potential impacts to Atlantic sturgeon from blasting, the project may need to utilize blasting for a small quantity of rock from the deep dredge area near the quay-side portion of the vessel berth area. The Commonwealth restates that blasting would only be utilized as a measure of last resort if other methods of rock removal are ineffective. Based upon drilling information from test borings installed within the project site, the Commonwealth anticipates that most of the rock that requires removal from the dredge footprint of the project can be removed using conventional dredging methods or through non-blasting rock removal techniques. However, the possibility does exist that some small volume of rock may need to be removed using blasting techniques. The blasting technique the Commonwealth anticipates utilizing involves the drilling of a series of small blast holes into the rock surface to the depth of desired removal at regular intervals (approximately every 8-15 feet). A small amount of explosive material would then be installed into the blast holes, tamped and covered, and detonated to fracture the rock so that it could be removed using conventional dredging methods.

NMFS recommends that blasting activities occur between November and January 15 to avoid impacts to the various noted species, or to implement engineering controls if blasting is to occur outside that window to mitigate the potential for the noted blasting activities impacting the resource. Because the critical path for this project timeline precludes the Commonwealth from ruling out blasting activities (should they be needed) outside the blasting window, the Commonwealth proposes to implement the following engineering controls to mitigate the potential for the noted blasting activities impacting the Atlantic Sturgeon resource:

- Prior to any potential blasting, the Commonwealth will conduct acoustical modeling to demonstrate that in-water noise levels at the zone of passage will not exceed peak pressure and impulse pressure thresholds for physiological impacts or mortality (less than or equal to 75.6 psi peak pressure levels and less than or equal to 18.4 psi-msec impulse pressure levels).

- Should modeling indicate that acoustical noise levels from blasting activities will exceed the levels indicated above at the zone of passage, then additional engineering controls in the form of noise attenuating bubble curtains between the blast work area and the zone of passage would be employed for work that would occur outside the November to March timeframe.

Shellfish

NMFS has correctly noted that multiple shellfish species in New Bedford Harbor are impacted by the proposed project but that the mitigation plan focuses on quahogs only. There are a couple of reasons for this approach. First, the project area was sampled for shellfish and the dominant species captured was quahog (*Mercenaria mercenaria*). Second, a goal of the mitigation proposed was to be as on-site as possible, so all mitigation activity was targeted in the City of New Bedford. Typically once a transplant is conducted, there is a period of time during which the restoration site is closed to shellfishing to protect the newly planted shellfish. The city already has large, permanent shellfish closures due to poor water quality and relatively little water space, so the mitigation strategy was designed to minimize additional closures while maximizing the number of shellfish planted.

Third, mono-specific quahog transplanting was the most efficient approach since quahogs can tolerate a wide range of depth, sediment type, and water quality conditions. Fourth, another goal of the proposed mitigation is to implement the plan in a timely fashion to limit time lag (the time period between the original loss of ecosystem function and the restoration of ecosystem function). Because of the resilience of quahogs, the transplant success rate is more predictable than with other species.

Finally, the infrastructure to culture and grow-out seed at the scale of this project (millions of seed each year) is not commonplace. With substantial capital investment, the Commonwealth has repurposed its former lobster hatchery to accommodate the anticipated culture of quahogs. The existing infrastructure will be fully utilized focusing on a single species.

However, at the recommendation of NMFS, the Commonwealth has committed to include oyster reseeding outside the New Bedford Hurricane Barrier. It is envisioned that an "oyster reef" will be created in order to mitigate for the lost oyster habitat at South Terminal. A technical team from the Commonwealth's Division of Marine Fisheries and NMFS will meet and collaborate on the establishment and design of the oyster mitigation plan.

Winter Flounder

Winter flounder spawn in shallow estuarine waters in the late winter and early spring. The eggs are demersal and adhesive, and have well-recognized vulnerability to sedimentation (Berry et al. 2003). The Commonwealth has had significant experience with the use of engineering controls in New Bedford Harbor through the work that has previously been conducted as part of the Superfund State Enhanced Remedy (SER) for navigational dredging. As part of the SER dredging program, the Commonwealth and

the USEPA established a set of SER "Performance Standards" (detailed in the Commonwealth's restated application to USEPA) that guide all work under the SER process in the Harbor. The SER Performance Standards prescribe a set of activities that must be implemented when necessary beneficial cleanup dredging occurs during a time of year restriction period. These standards include the actions recommended by NMFS in its August 21, 2012 letter to EPA:

- The use of an environmental bucket for dredging of fine grained materials;
- The use of silt curtains (or equivalent) combined with turbidity monitoring with action levels.

The Commonwealth is aware that NMFS has raised concerns that the mitigation efforts that would be undertaken through the SER process for this project would not fully take into account impacts to demersal eggs from Winter Flounder that might stray into pending dredge work zones during the spawning season (January 15 through May 31) and lay eggs in the portions of the work zone that are at the spawning depth range (generally shallower than 16-feet).

The Commonwealth notes that for projects of relatively short incursion into the "no-dredge window," the likelihood that this scenario would produce significant impact to the species in the area is low. However, in recognition of the special circumstances associated with this project, the Commonwealth is proposing to adopt a series of enhanced engineering controls that consist of:

- Cordoning off the entire depth-relevant time-critical construction areas noted above during the time of year that Winter Flounder could potentially be spawning (January 15 through May 31) to make those areas unavailable to spawning fish through the spawning period. The areas would be cordoned off by installing a subsurface curtain wall consisting of a combination of silt curtains (which would be installed and held into place by anchors to assure effectiveness) and bubble curtains (in areas where navigational servitude will need to be maintained). The silt and bubble curtain equipment will be weighted along their entire length (at the benthic end) to ensure that the deterrent curtain extends the full range of the water column throughout the full tidal range, and does not allow fish to pass under it. A mid-curtain positive buoyancy system will be added to the silt curtain system to hold curtain folds off the bottom during low tidal ranges to reduce the potential for the silt curtains causing siltation issues.
- Use of an acoustic fish "startle" deterrent system (EFSS by Sonalysts or similar) within the time-critical work area prior to the January 15 cordoning-off date to remove existing fish from the zone prior to installing the curtain wall. Additionally, a "tactile fish startle system" (TFSS) will be utilized to remove benthic demersal fish from the work zone prior to cordoning off the work zone.

The tactile fish startle system will utilize a curtain of streamers that reach to the benthic surface deployed from a floating boom pulled from a set of moving vessels to encourage benthic demersal fish (such as winter flounder) to move out of the area prior to it being cordoned off. Both the EFSS and TFSS equipment will be deployed from shallow draft vessels roving through the area to be cordoned off along a grid pattern with 25-foot line spacing.

- Conducting periodic weekly camera and diving inspections of the silt curtain/bubble curtain wall to ensure its integrity, and completing necessary repairs in a timely fashion for damage or entanglement of the curtain wall that would impeded its effectiveness.
- Conducting periodic weekly camera and acoustic fish detection system (AFDS) surveys of the enclosed work area (on a 20-foot grid pattern) to determine if fish remain in the area after the EFSS and TFSS systems have been employed. If the results of the camera and AFDS survey indicate that fish remain within the work zone, a second set of EFSS and TFSS transits will be completed.
- The Commonwealth recognizes that the activities proposed herein will constitute a pilot program to evaluate whether these techniques will be successful on future projects. As such, the Commonwealth commits to filing information concerning the fish deterrent activities described in this section, including: documentation of curtain wall and fish detection survey monitoring activities in a weekly report to the EPA, the SER committee, and NMFS; and preparation of a report of the activities at the conclusion of the project that describes the activities undertaken, the effectiveness of the activities, and any modifications made to the activities during the work period.

The above noted enhanced engineering controls would be utilized concurrently with the typical SER Performance Standard actions of water quality monitoring (both inside and outside the curtained area), and use of the environmental bucket for the dredging of fine grained sediments that can be dredged with the environmental bucket – to ensure that silt suspension from the dredging process is minimized to the extent practicable. The Commonwealth believes that the use of this combined set of engineering controls would effectively mitigate the impacts from dredging during sensitive time periods for Winter Flounder. The enhanced engineering controls would also have the added benefit of mitigating impacts of dredging on anadromous fish species that might be present in the Harbor, as the controls would deter fish from entering the work area and reduce the potential for siltation in the water column.

Finally, the Commonwealth commits to work with NMFS on the creation of a technical working group that would finalize the details of the pilot monitoring regime proposed, to ensure the integrity of the winter flounder protection program.

Conclusion

The Commonwealth believes that the measures proposed will allow the project to advance along a timeline that meets the project's intended purpose and need while protecting and minimizing any temporary impacts the construction might have on the fisheries resources found in New Bedford Harbor. The Commonwealth believes that the extensive clean-up, coupled with the mitigation and engineering controls, provides the best long term benefits to the fisheries resources present in New Bedford Harbor.

The Commonwealth's Natural Resource agencies, including the Division of Marine Fisheries, shares a common mission and goal as both EPA and NMFS, and we are committed to a constructive collaboration with you to protect the natural resources of New Bedford Harbor as we construct this historic project. We request for EPA to concur with the information and analysis contained in this letter that was developed in partnership with the National Marine Fisheries Service.

As always, the Commonwealth is available to discuss any aspect of the project approach presented herein, and we look forward to working with you and your staff to advance the Final Decision for the project in the near future.

Sincerely,

Richard K. Sullivan Jr.
Secretary

Paul J Diodati

Paul Diodati
Director, MA Division of Marine Fisheries

cc: John Bullard, NOAA's Northeast Regional Administrator

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ATTACHMENT B

Underwater Acoustic Modeling of Construction Activities

Marine Commerce South Terminal in New Bedford, MA

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1. Introduction

Construction of the proposed Marine Commerce Terminal (South Terminal) in New Bedford, MA, will require pile driving, non-explosive rock removal, and (possibly) explosive rock removal. This report presents the results of an underwater acoustic modeling study of the proposed construction site. JASCO Applied Sciences (JASCO) carried out this study for Apex Companies, LCC (Apex) in support of the construction project's biological assessment for the Atlantic sturgeon (*Acipenser oxyrinchus*). Interpretation of potential effects of noise on marine life, including Atlantic sturgeon, is outside the scope of this report.

The model scenarios were chosen to evaluate precautionary distances to threshold levels for each construction activity, at the time of year when the water conditions allow sound to propagate the farthest from the source. Five scenarios were modeled:

- One pile driving scenario at Site 2, along the extended South Terminal bulkhead,
- Two non-explosive rock removal scenarios at Sites 1 and 2, within South Terminal dredge footprint, and
- Two explosive rock removal scenarios at Site 2, with and without a surrounding bubble curtain used as a mitigation system (Figure 1).

The sound levels estimated from this study are presented in two formats: as contour maps of the sound fields that show the directivity and range to various sound level thresholds and as maximum and 95% distances to some sound level thresholds. The distances from the sound sources to sound level thresholds, representing pile driving and non-explosive rock removal operations, are provided for:

- Peak sound pressure level (SPL) of 206 dB re 1 μPa,
- Cumulative sound exposure level (cSEL) of 187 dB re 1 $\mu Pa^2 \cdot s$,
- root-mean-square (rms) SPL from 200 to 120 dB re 1 μPa in 10 dB steps, and
- Sound exposure level (SEL) from 200 to 120 dB re 1 μPa in 10 dB steps (for impulse sound sources only).

The distances to sound level thresholds for the use of explosives are provided for:

- Peak pressure of 75.6 psi, and
- Impulse level of 18.4 psi-msec.

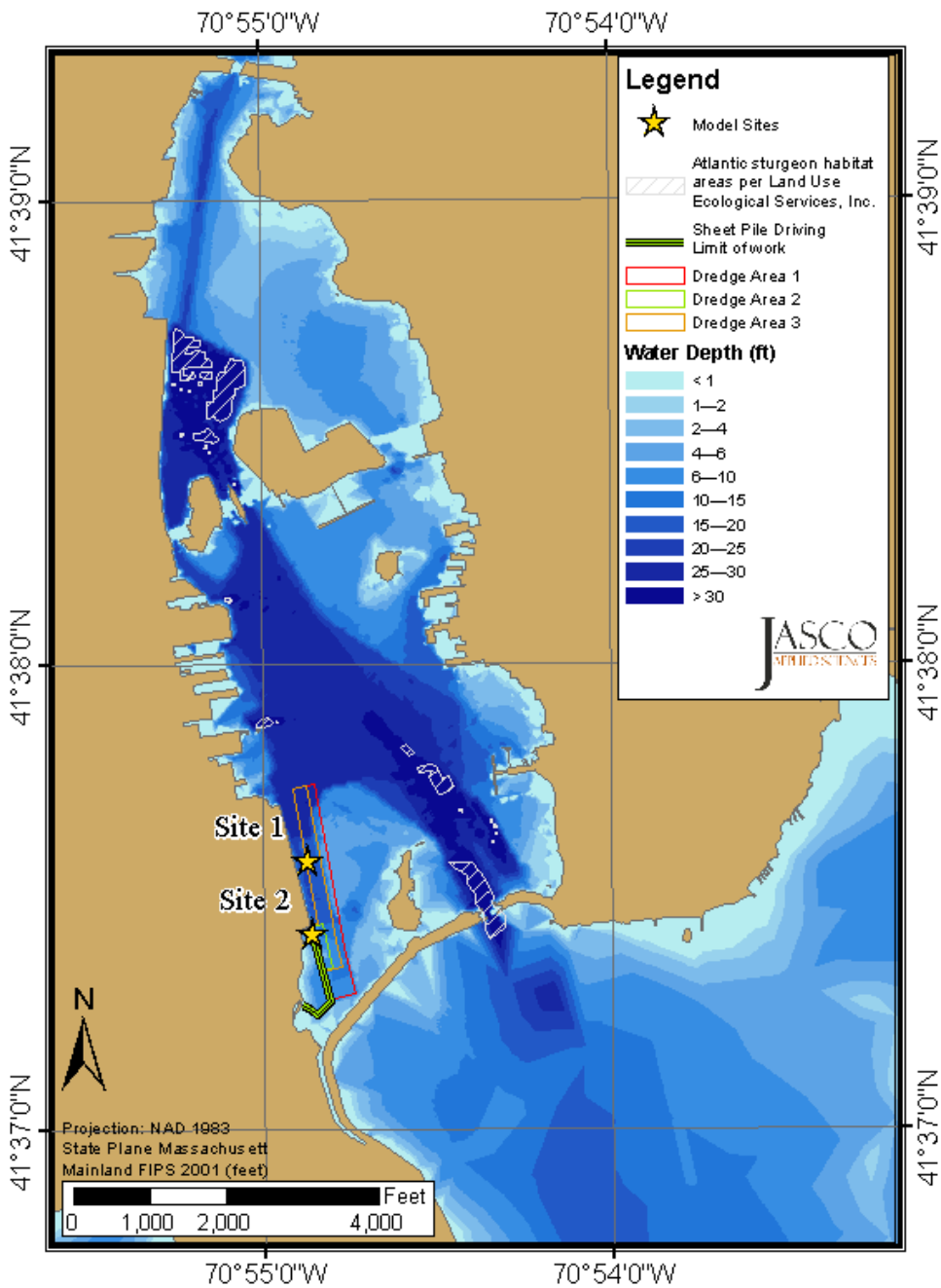

Figure 1. Location of the proposed Marine Commerce Terminal ( ) and the model scenario locations (☆) in New Bedford Harbor, MA.

1.1. Fundamentals of Underwater Acoustics

Sound is the result of mechanical vibration waves traveling through a fluid medium such as air or water. These vibration waves generate a time-varying pressure disturbance that oscillates above and below the ambient pressure. Sound waves may be perceived by the auditory system of an animal, or they may be measured with an acoustic sensor (a microphone or hydrophone). Water conducts sound over four times faster than air due to its lower compressibility; the speed of sound travelling in water is roughly 4900 ft/s, compared to 1100 ft/s in air. Sound is used

extensively by marine organisms for communication and for sensing their environment. Humans may use sound purposely to probe the marine environment through technologies like sonar; more often, human activities such as marine construction produce underwater sound as an unintended side effect.

Sources of underwater sound can be mechanical (e.g., a ship), biological (e.g., a whale) or environmental (e.g., rain). *Noise*, in general parlance, refers to unwanted sound that may affect humans or animals. Noise at relatively low levels can form a background that interferes with the detection of other sounds; at higher levels, noise can also be disruptive or harmful. Common sources of naturally occurring underwater environmental noise include wind, rain, waves, seismic disturbances, and vocalizations of marine fauna. Anthropogenic (i.e., manmade) sources of underwater noise include marine transportation, construction, geophysical surveys, and sonar. Underwater noise usually varies with time and location.

1.1.1. Properties of Sound

The fundamental properties of sound waves are amplitude, frequency, wavelength, and intensity. Frequency of a sound wave, f, is the rate of pressure oscillation per unit of time. Amplitude of a sound wave, A, is the maximum absolute pressure deviation of the wave. If c is the speed of sound in a medium, then the pressure disturbance, P, due to a plane harmonic sound wave (Figure 2) at time t and location x is:

$$P(x,t) = A\cos(2\pi f(x/c - t)) \tag{1}$$

The wavelength, λ, is the distance traveled by a sound wave over one complete cycle of oscillation. For plane harmonic sound waves, the wavelength is equal to the frequency divided by the speed of sound:

$$\lambda = \frac{f}{c} \tag{2}$$

Harmonic waves are fundamentally in acoustics because a well-known mathematical law (Fourier's theorem) states that any arbitrary waveform can be represented by the superposition of harmonic waves.

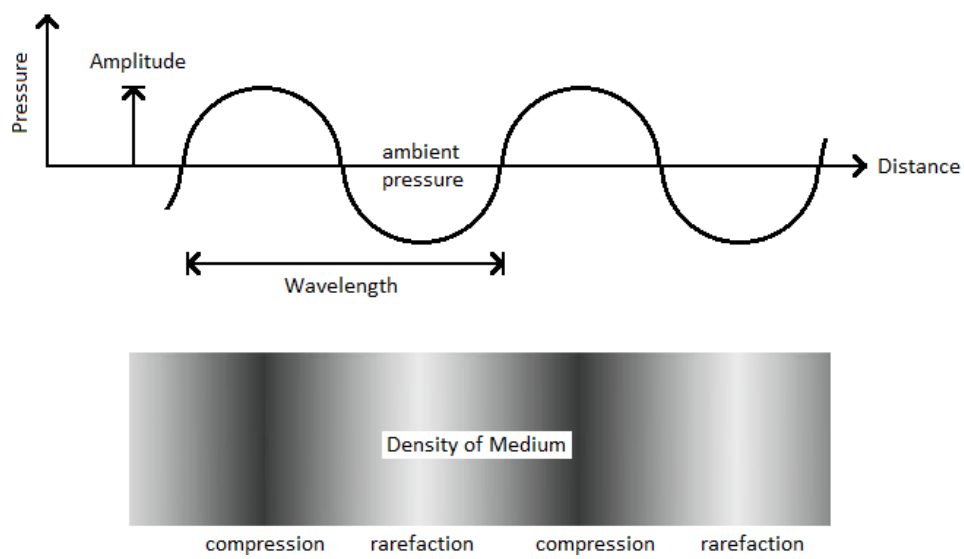

Figure 2. Snapshot of the pressure disturbance due to a plane harmonic sound wave.

The intensity of a traveling sound wave is the acoustic power per unit area carried by the wave. In general, the intensity of a sound wave is related to the wave's amplitude, but it also depends on the compressibility and density of the acoustic medium. The loudness of a sound is related to the intensity; however, loudness is a subjective term that refers to the *perception* of sound intensity, rather than to the actual intensity itself. For humans and other animals, perceived loudness also depends on the frequency and duration of the sound.

1.1.2. Acoustic Metrics

Sound pressure and intensity are commonly measured on the decibel (dB) scale. The decibel scale is a logarithmic scale that expresses a quantity relative to a predefined reference quantity. Sound pressure in decibels is expressed in terms of the sound pressure level (SPL, symbol L_p):

$$L_p = 20\log_{10}\left(P / P_{ref}\right) \tag{3}$$

where P is the pressure amplitude and P_{ref} is the reference sound pressure. For underwater sound, the reference pressure is 1 μPa (i.e., 10^{-6} Pa or 10^{-11} bar). In most cases, sound intensity is directly proportional to the mean square of the sound pressure (i.e., $I \propto \langle P^2 \rangle$); therefore, SPL is considered synonymous with sound intensity level.

The decibel scale for measuring underwater sound is different than for measuring airborne sound. Airborne decibels are based on a standard reference pressure of 20 μPa, which is 20 times greater than the hydroacoustic reference pressure of 1 μPa. Furthermore, due to differences in compressibility and density between the two media, the impedance relationship between sound pressure and sound intensity is different in air than in water. Accounting for these differences in reference pressure and acoustic impedance, for a sound wave with the same intensity in both media, the hydroacoustic decibel value (in dB re 1 μPa) is about 63 dB greater than the airborne decibel value (in dB re 20 μPa).

Sounds that are composed of single frequencies are called "tones." Most sounds are generally composed of a broad range of frequencies ("broadband" sound) rather than pure tones. Sounds with very short durations (less than a few seconds) are referred to as "impulsive." Such sounds typically have a rapid onset and decay. Steady sounds that vary in intensity only slowly with time, or that do not vary at all, are referred to as "continuous."

1.1.2.1. Metrics for Continuous Sound

Continuous sound is characterized by gradual intensity variations over time, e.g., the propeller noise from a transiting ship. The intensity of continuous noise is generally given in terms of the root-mean-square (rms) SPL. Given a measurement of the time varying sound pressure, $p(t)$, for a given noise source, the rms SPL (symbol L_p) is computed according to the following formula:

$$L_p = 10\log_{10}\frac{1}{T}\int_T p(t)^2\,dt / P_{ref}{}^2 \tag{4}$$

In this formula, T is time over which the measurement was obtained. Figure 3 shows an example of a continuous sound pressure waveform and the corresponding rms sound pressure.

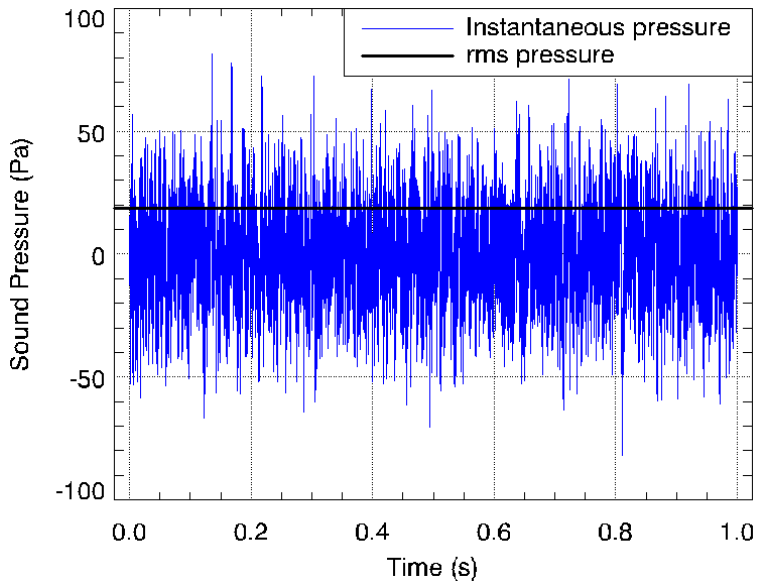

Figure 3. Example waveform showing a continuous noise measurement and the corresponding root-mean-square (rms) sound pressure.

1.1.2.2. Metrics for Impulsive Sound

Impulsive, or transient, sound is characterized by brief, intermittent acoustic events with rapid onset and decay back to pre-existing levels (within a few seconds), e.g., noise from impact pile driving. Impulse sound levels are commonly characterized using three different acoustic metrics: peak pressure, rms pressure, and sound exposure. The peak SPL (symbol L_{pk}) is the maximum instantaneous sound pressure level measured over the impulse duration:

$$L_{\mathrm{pk}} = 20\log_{10}\left(\max\left|p(t)\right| / P_{ref}\right) \tag{5}$$

In this formula, $p(t)$ is the instantaneous sound pressure as a function of time, measured over the impulse duration $0 \le t \le T$. This metric is very commonly quoted for impulsive sounds but does not take into account the duration or bandwidth of the noise.

The rms SPL may be measured over the impulse duration according to the following equation:

$$L_p = 10\log_{10}\left(\frac{1}{T}\int_T p(t)^2\,dt / P_{ref}^2\right) \tag{6}$$

Some ambiguity remains in how the duration T is defined, because in practice the beginning and end of an impulse can be difficult to identify precisely. In studies of impulsive noise, T is often taken to be the interval over which the cumulative energy curve rises from 5% to 95% of the total energy. This interval contains 90% of the total energy (T_{90}), and the SPL computed over this interval is commonly referred to as the 90% rms SPL (L_{p90}). The relative energy, $E(t)$, of the impulse is computed from the time integral of the square pressure:

$$E(t) = \int_0^t p(\tau)^2\,d\tau / P_{ref}^2 \tag{7}$$

According to this definition, if the time corresponding to n% of the total relative energy of the impulse is denoted t_n, then the 90% energy window is defined such that $T_{90} = t_{95}–t_5$. Figure 4 shows an example of an impulsive sound pressure waveform, with the corresponding peak pressure, rms pressure, and 90% energy time interval.

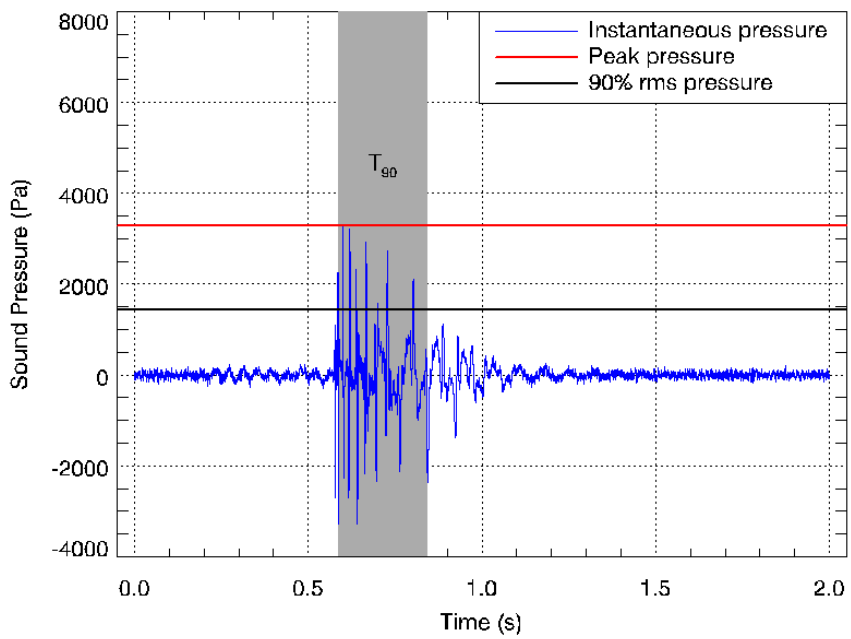

Figure 4. Example waveform showing an impulsive noise measurement. Horizontal lines indicate the peak pressure and 90% root-mean-square (rms) pressure for this impulse. The gray area indicates the 90% energy time interval (T_{90}) over which the rms pressure is computed.

The sound exposure level (SEL, symbol L_E) is a measure of the total sound energy contained in one or more impulses. The SEL for a single impulse is computed from the time-integral of the squared pressure over the impulse duration:

$$L_E = 10\log_{10}\left(\int_{T_{100}} p(t)^2\,dt / P_{ref}^2\right) = 10\log_{10}\left(E\left(T_{100}\right)\right) \tag{8}$$

Unlike SPL, the SEL is generally applied as a dosage metric, meaning that its value increases with the number of exposure events. The cumulative SEL (cSEL) for multiple impulses (symbol $L_E^{(\Sigma)}$) is computed from the linear sum of the SEL values:

$$L_E^{(\Sigma)} = 10\log_{10}\left(\sum_{n=1}^{N} 10^{L_E^{(n)}/10}\right) \tag{9}$$

where N is the total number of impulses, and $L_E^{(n)}$ is the SEL of the nth impulse event. Alternatively, given the mean (or expected) SEL for single impulse events, $\langle L_E \rangle$, the cumulative SEL from N impulses may be computed according the following formula:

$$L_E^{(\Sigma)} = \langle L_E \rangle + 10\log_{10}(N) \tag{10}$$

Sound levels for impulsive noise sources (i.e., impact hammer pile driving) presented in this report refer to single pulse. Because the 90% rms SPL and SEL for a single impulse are both computed from the integral of square pressure, these metrics are related by a simple expression that depends only on the duration of the 90% energy time window T_{90}:

$$L_E = L_{p90} + 10\log_{10}(T_{90}) + 0.458 \tag{11}$$

In this formula, the 0.458 dB factor accounts for the remaining 10% of the impulse energy that is excluded from the 90% time window.

The impulse metric is sometimes used for assessment of the impact of the acoustic wave from an explosion. The impulse is the time integral of pressure through the largest positive phase of a pressure waveform (CSA 2004):

$$I = \int_0^{\tau} p(t)dt \tag{12}$$

In this formula, $p(t)$ is the instantaneous sound pressure as a function of time and τ is the end time of the largest positive phase of the pressure waveform. The impulse has units of pounds per square-inch-seconds (psi·s) or pounds per square-inch-milliseconds (psi·msec).

1.1.3. Source Level and Transmission Loss

Sources of underwater noise generate radiating sound waves whose intensity generally decays with distance from the source. The dB reduction in sound level that results from propagation of sound away from an acoustic source is called propagation loss or transmission loss (TL). The loudness or intensity of a noise source is quantified in terms of the source level (SL), which is the sound level referenced to some fixed distance from a noise source. The standard reference distance for underwater sound is 1 m. By convention, transmission loss is quoted in units of dB re 1 m and underwater acoustic source levels are specified in units of dB re 1 μPa at 1 m. In the source-path-receiver model of sound propagation, the received sound level RL at some receiver position **r** is equal to the source level minus the transmission loss along the propagation path between the source and the receiver:

$$\mathrm{RL}(\mathbf{r}) = \mathrm{SL} - \mathrm{TL}(\mathbf{r}) \tag{13}$$

1.1.4. Spectral Density and 1/3-Octave Band Analysis

The discussion of noise measurement presented so far has not addressed the issue of frequency dependence. The sound power per unit frequency of an acoustic signal is described by the power spectral density (PSD) function. The PSD for an acoustic signal is normally computed via the Discrete Fourier Transform (DFT) of time-sampled pressure data. The units of PSD are 1 μPa^2/Hz or dB re 1 μPa^2/Hz. For practical quantitative spectral analysis, a coarser representation of the sound power distribution is often better suited. In 1/3-octave band analysis, an acoustic signal is filtered into multiple, non-overlapping passbands before computing the SPL. These 1/3-octave bands are defined so that three adjacent bands span approximately one octave (i.e., a doubling) of frequency. Figure 5 shows an example of power spectral density levels and corresponding 1/3-octave band pressure levels for an ambient noise recording.

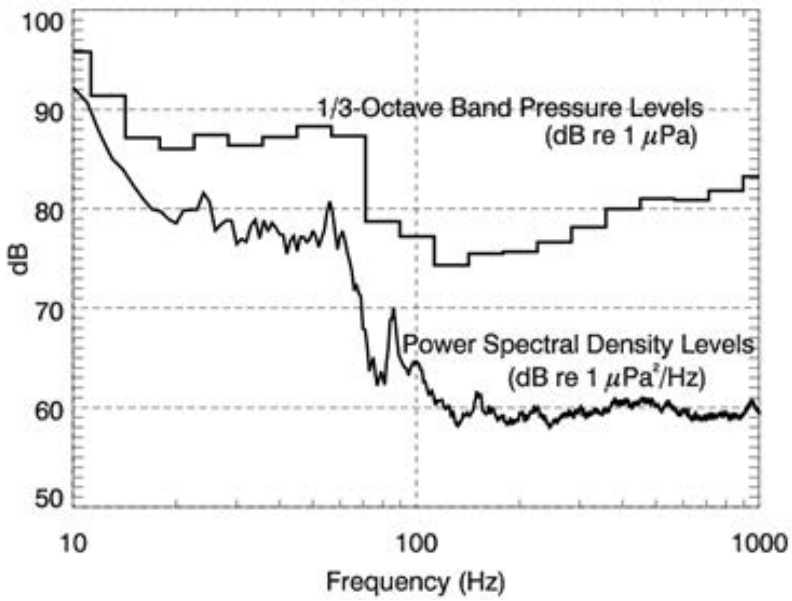

Figure 5. Example power spectrum of ambient noise and the corresponding 1/3-octave band sound pressure levels. Frequency is plotted on a logarithmic scale, so the 1/3-octave bands are larger at higher frequencies.

Standard center frequencies, f_c, for 1/3-octave passbands are given by:

$$f_c(n) = 10^{n/10} \quad n = 1, 2, 3... \tag{14}$$

Nominal 1/3-octave band center frequencies, according to ISO standards, for the range relevant to this study are listed in Table 1. The SPL inside a 1/3-octave band, $L_{pb}(f_c)$, is related to the average PSD level inside that frequency band, $L_{ps}^{(avg)}(f_c)$, by the bandwidth, Δf:

$$L_{ps}^{(avg)}(f_c) = L_{pb}(f_c) - 10\log_{10}(\Delta f) \tag{15}$$

The bandwidth of a 1/3-octave band is equal to 23.1% of the band center frequency (i.e., $\Delta f = 0.231 f_c$). Spectrum density levels and band levels are not limited to measurements of sound pressure: they may also, with appropriate selection of reference units, be given for SEL.

Table 1. The nominal center frequencies of 1/3-octave bands, from 10 Hz to 20 kHz.

Band Number	Center Frequency (Hz)	Band Number	Center Frequency (Hz)	Band Number	Center Frequency (Hz)	Band Number	Center Frequency (Hz)
10	10	20	100	30	1,000	40	10,000
11	12.5	21	125	31	1,250	41	12,500
12	16	22	160	32	1,600	42	16,000
13	20	23	200	33	2,000	43	20,000
14	25	24	250	34	2,500		
15	31.5	25	315	35	3,150		
16	40	26	400	36	4,000		
17	50	27	500	37	5,000		
18	63	28	630	38	6,300		
19	80	29	800	39	8,000		

1.2. Acoustic Impact Criteria

The acoustic impact criteria considered in this report were based on the recommendation from the National Marine Fisheries Service (NMFS). Currently, NMFS has no formal criteria for assessment of injury, mortality, or behavioral effect on fish created by continuous sound; however, NMFS, through correspondence with Apex, requested that the same impact criteria for impact pile driving (i.e., for impulsive sound) be considered for vibratory pile driving and non-explosive rock removal (i.e., for continuous sound). NMFS uses dual criteria for assessment of injury to finfish by impact hammer pile driving. These criteria, derived from the agreement by the Fisheries Hydroacoustic Working Group (FHWG 2008), are:

- Peak SPLs ≥ 206 dB re 1 μPa or cSELs ≥ 187 dB re 1 $\mu Pa^2 \cdot s$ over 24 hours are estimated to create injury or mortality to fish, and
- rms SPLs ≥ 150 dB re 1 μPa are estimated to have behavioral effects on fish.

By convention, SELs for continuous sources are considered over a 1 s interval, thus are equal to rms SPLs (see Section 1.1.2); therefore, distances to the injury or mortality threshold of 187 dB re 1 $\mu Pa^2 \cdot s$ (cSEL over 24 hours) may be greater than that of behavioral effects threshold on fish (rms SPL of ≥ 150 dB re 1 μPa). Although these criteria are unusual for a continuous source[1], these were the only criteria considered in this report.

Currently, NMFS has no formal criteria for assessment of hydroacoustic impacts of underwater explosion on finfish. The peak pressure levels of ≤ 75.6 psi and impulse levels of ≤ 18.4 psi-msec were previously reported to create no injury or mortality to fish (Bullard 2012, Mosher 1999). These levels were therefore used as impact criteria in this report.

1.3. Air Bubble Curtains

Noise attenuation (or mitigation) systems consist of strategies that reduce impacts of construction activities on the surrounding environment. For underwater construction activities, these systems are the primary method for reducing the sound levels of waterborne pressure waves.

Air bubble curtains consist of one or more bubble rings surrounding the underwater activity. For example, the application of air bubble curtains for reducing underwater sound levels from pile driving has been studied extensively, particularly for large diameter piles (Vagle 2003, Nehls et al. 2007, CALTRANS 2009). The operating principle of this mitigation method is that a cloud of air bubbles changes the acoustic properties of the water, reducing transmission of pressure waves from the sound source into the surrounding water. Effectiveness of bubble curtains is variable and depends on many factors, including the bubble layer thickness, the total volume of injected air, the size of the bubbles relative to the sound wavelength, and whether the curtain is completely closed. Use of a confined air bubble curtain ensures that the air bubbles are shielded from water currents and the sound source remains completely and consistently enshrouded in bubbles. Since New Bedford Harbor has weak currents and the proposed bubble curtain was

[1] The cSEL criteria for nonpulse (continuous) sound are generally much higher than for impulsive sound (by 17 dB for marine mammals; Southall 2007).

specially design to prevent gaps of air bubbles above the seabed, the attenuation from the proposed bubble curtain is expected to be comparable to that of a confined bubble curtain.

2. Methods

2.1. Model Scenarios

Five scenarios were modeled (Figure 1, Table 2):

- one pile-driving scenario,
- two non-explosive rock removal scenarios, and
- two explosive rock removal scenarios.

The model scenarios evaluate precautionary distances to sound level thresholds at the time of year when the water conditions allow the sound to propagate the farthest from the source. For comparison purpose, each type of operation was modeled at Site 2 (northern edge of the proposed terminal; Figure 1); explosive rock removal was modeled with and without the estimated attenuation from an air bubble curtain. Non-explosive rock removal operations were also modeled at Site 1 (within the northern section of the South Terminal dredge footprint; Figure 1).

Table 2. List of model scenarios. Site 2 is located at the north edge of proposed South Terminal. Site 1 is located within the northern section of the South Terminal dredge footprint (Figure 1).

Scenario	Sound Source	Location	Air Bubble Curtain
Pile Driving			
1	Vibratory hammer	Site 2	Off
Non-Explosive Rock Removal			
2	Cutter-head dredge	Site 1	Off
3	Cutter-head dredge	Site 2	Off
Explosive Rock Removal			
4	Explosive charges (10 to 50 lbs)	Site 2	Off
5	Explosive charges (10 to 50 lbs)	Site 2	On

2.2. Acoustic Source Levels

2.2.1. Pile Driving

Documentation provided by Apex specified that sheet piles (type AS-500-12.7 (20 inch) or AZ-14-700 (28 inch)) will be driven to form the bulkhead of the proposed South Terminal. Later, 24–36 inch diameter steel piles will be set into pre-drilled holes in front of the sheet pile. The piles will be driven using a vibratory system; however, the exact drilling equipment was undecided at the time of this study.

The energy required to drive a pile depends on the pile size and the soil resistance encountered; therefore, the noise from the pile driving operations is expected to vary throughout the operation. At first, the pile penetration will be shallow and there will be little soil resistance. At the final stage, when the pile penetration approaches the projected depth, the resistance will be strongest

and higher energy is needed to drive the pile. The maximum noise levels from the pile driving are expected at the latest stage of driving for each individual pile (Betke 2008).

Measurements of underwater sound levels reported by Illingworth & Rodkin (2007) were used to estimate sound levels from vibratory hammer on 24-inch sheet piles. Review and analysis of past measurements is currently the best available method for estimating source levels for use in predictive models of pile driving. Technical guidelines generally advocate estimating piling source levels from past measurements (CALTRANS 2009, §4.6.2, WSDOT 2010b, §7.2.4). JASCO has applied this method to several projects to predict the underwater noise from pile driving activities (Gaboury et al. 2007a, 2007b, Austin et al. 2009, Erbe 2009, MacGillivray et al 2011).

The reported levels were back-propagated to a reference distance of 3.28 ft (1 m) from the source assuming spherical spreading loss ($20\log R$) up to a distance equal to the water depth and cylindrical spreading loss ($10\log R$) thereafter (where R [m] is the range from the source).

2.2.2. Rock Removal–Non-Explosive

A mechanical or hydraulic type dredge with an enclosed bucket will remove surficial sediment within the South Terminal dredge footprint (dredge areas 1–3 in Figure 1). If the rock is too hard for removal with conventional dredges, different non-explosive rock removal techniques may be used, including:

- Hydraulic impact hammering (Hoe Ram),
- Drilling and fracturing of rock,
- Use of large backhoe, and
- Use of a cutter-head.

The exact specification of the non-explosive rock removal equipment was unknown at the time of this study; thus, the estimated source levels from the different activities considered were compared and the "loudest" technique was modeled to present precautionary estimates of radii to level thresholds.

2.2.3. Rock Removal–Explosives

If non-explosive rock removal methods do not allow for dredging to reach the desired water depth, explosives may be used to fragment the bedrock and facilitate dredging.

The peak pressure and impulse of the pressure waveform from a blast can be predicted with the UnderWater Calculator spreadsheet developed by Dzwilewski and Fenton (2003), which calculates various acoustic wave metrics of the sound from a blast. The calculations can be done for an arbitrary distance from the source. The tool was designed to predict the acoustic impact of pile removal operations that involved placing a charge inside a pipe pile.

The Calculator employs empirical equations for the peak pressure (P_{pk}, in psi) and the impulse (I, in psi-msec; Swisdak 1978) from a blast:

$$P_{\mathrm{pk}}(r) = 145.0\, K_P \left(\frac{W^{1/3}}{r} \right)^{\alpha_P} \tag{16}$$

$$I(r) = 145.0 W^{1/3} K_I \left(\frac{W^{1/3}}{r} \right)^{\alpha_I} \tag{17}$$

where W is the effective weight of the explosive charge (in kilograms), r is the slant range from the blast (in meters), and K_P, K_I, α_P, and α_I are coefficients specific to a given explosive. These equations were developed for a blast detonated in the water column. To simulate the shockwave from a charge buried in the sediment, the effective weight of the charge must be adjusted. The kinetic energy coupled into the water is reduced because a portion of the blast energy is absorbed by non-elastic deformations of the sediment. Dzwilewski and Fenton (2003) performed several numerical model runs with the Eulerian hydrocode CTH, a three-dimensional shock wave physics code (McGlaun et al. 1990), to quantify the explosive coupling efficiency for a charge buried in compact clay sediments and for a charge placed inside a steel pipe driven into clay sediments. The coupling efficiency for a 50-lbs C-4 charge in stiff clay sediments was estimated at 79%. The same charge placed inside a 36-inch diameter pile with 1.5-inch wall thickness in clay had 39% coupling efficiency (Dzwilewski and Fenton 2003). The coupling efficiency increased with the charge size.

2.3. Air Bubble Curtain

The mitigation effect of a bubble curtain on explosive rock removal activities was estimated from the results of field experiments. Nützel (2008) reported results of a controlled blast experiment in which the acoustic wave impact was monitored at 377 ft (115 m) from the blast site at 43 ft (13 m) water depth. The data from four hydrophones placed at 13, 20, 26, and 33 ft (4, 6, 8, and 10 m) below the sea surface were recorded. The experiment included three charge sizes: 0.22, 2.2, and 33 lbs (0.1, 1, and 15 kg). Five setups were considered:

- no bubble curtain,
- a single bubble curtain at 25 ft (7.5 m) from the charge with 45.2 ft^3/min (4.2 m^3/min) air supply rate, and
- single, double and triple layer bubble curtains with layers separated by 6.5 ft (2 m) with 215 ft^3/min (20 m^3/min) total air supply rate.

The mitigation effect of the bubble curtain measured at different depths varied between 9.5 and 19.9 dB (Nützel 2008). This study assumes a bubble curtain will have a 12 dB mitigation effect on the shockwave from a blast.

2.4. Sound Propagation Models

Underwater sound propagation (i.e., transmission loss) at frequencies of 10 Hz to 20 kHz was predicted with JASCO's Marine Operations Noise Model (MONM). MONM computes received SEL for directional impulsive sources at a specified source depth.

2.4.1. Marine Operations Noise Model

At frequencies ≤2 kHz, MONM computes acoustic propagation via a wide-angle parabolic equation solution to the acoustic wave equation (Collins 1993) based on a version of the U.S. Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been

modified to account for an elastic seabed. The parabolic equation method has been extensively benchmarked and is widely employed in the underwater acoustics community (Collins et al. 1996). MONM-RAM accounts for the additional reflection loss at the seabed due to partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces, and it includes wave attenuations in all layers. MONM incorporates the following site-specific environmental properties: a bathymetric grid of the modeled area, underwater sound speed as a function of depth, and a geoacoustic profile based on the overall stratified composition of the seafloor.

MONM-RAM's predictions have been validated against experimental data in several sound source verification programs conducted by JASCO (Hannay and Racca 2005, Aerts 2008, Funk et al. 2008, Ireland et al. 2009, O'Neill et al. 2010, Warner et al. 2010).

At frequencies ≥2 kHz, MONM employs the widely-used BELLHOP Gaussian beam ray-trace propagation model (Porter and Liu 1994) and accounts for increased sound attenuation due to volume absorption at these higher frequencies following Fisher and Simmons (1977). This type of attenuation is significant for frequencies higher than 5 kHz and cannot be neglected without noticeable effect on model results at long ranges from the source. MONM-BELLHOP accounts for the source directivity, specified as a function of both azimuthal angle and depression angle. MONM-BELLHOP incorporates site-specific environmental properties such as a bathymetric grid of the modeled area and underwater sound speed as a function of depth. In contrast to MONM-RAM, the geoacoustic input for MONM-BELLHOP consists of only one interface, namely the sea bottom. This is an acceptable limitation because the influence of the bottom sub-layers on the propagation of acoustic waves with frequencies above 2 kHz is negligible.

MONM computes acoustic fields in three dimensions by modeling transmission loss within two-dimensional (2-D) vertical planes aligned along radials covering a 360° swath from the source, an approach commonly referred to as N×2-D. These vertical radial planes are separated by an angular step size of $\Delta\theta$, yielding $N = 360°/\Delta\theta$ number of planes.

MONM treats frequency dependence by computing acoustic transmission loss at the center frequencies of 1/3-octave bands. Sufficiently many 1/3-octave bands, starting at 10 Hz, are modeled to include the majority of acoustic energy emitted by the source. At each center frequency, the transmission loss is modeled within each vertical plane (N×2-D) as a function of depth and range from the source. Third-octave band received (per-pulse) SELs are computed by subtracting the band transmission loss values from the directional source level (SL) in that frequency band. Composite broadband received SELs are then computed by summing the received 1/3-octave band levels.

The received SEL sound field within each vertical radial plane is sampled at various ranges from the source, generally with a fixed radial step size. At each sampling range along the surface, the sound field is sampled at various depths, with the step size between samples increasing with depth below the surface. The step sizes are chosen to provide increased coverage near the depth of the source and at depths of interest in terms of the sound speed profile. The received SEL at a surface sampling location is taken as the maximum value that occurs over all samples within the water column below, i.e., the maximum-over-depth received SEL. These maximum-over-depth SELs are presented as color contours around the source.

An inherent variability in measured sound levels is caused by temporal variability in the environment and the variability in the signature of repeated acoustic impulses (sample sound

source verification results are presented in Figure 6). While MONM's predictions correspond to the averaged received levels, precautionary estimates of the radii to sound level thresholds are obtained by shifting the best fit line (solid line in Figure 6) upward so that the trend line encompasses 90% of all the data (dashed line in Figure 6).

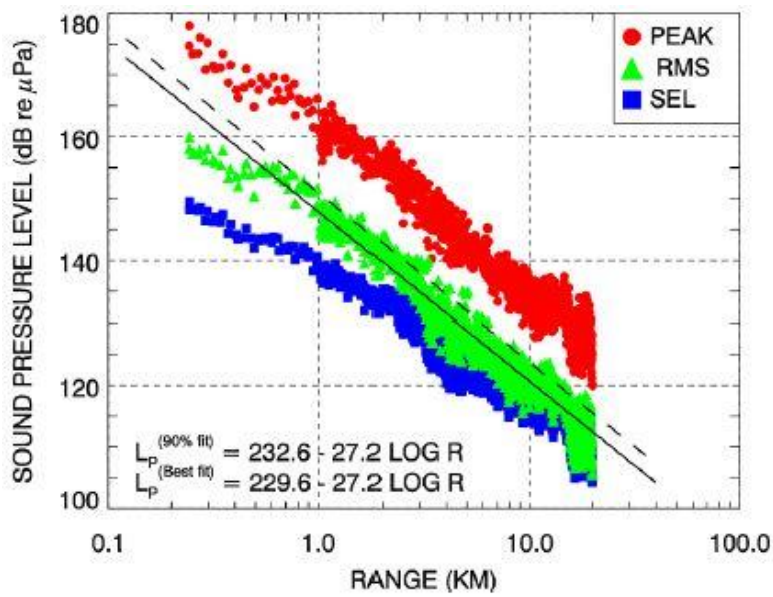

Figure 6. Peak and root-mean-square (rms) sound pressure level (SPL) and sound exposure level (SEL) versus range from a 20 in^3 airgun array. Solid line is the least squares best fit to rms SPL. Dashed line is the best-fit line increased by 3.0 dB to exceed 90% of all rms SPL values (90th percentile fit) (Ireland et al. 2009, Fig. 10).

2.4.2. Cumulative Sound Exposure Levels

While some impact criteria are based on per-pulse received energy at the subject's location, others account for the total acoustic energy to which marine life is subjected over a 24 h period. An accurate assessment of the cumulative acoustic field depends not only on the parameters of each pulse, but also on the number of pulses delivered in a given time period and the relative source position of the pulse. Quite a different issue, which is not considered here but bears mentioning as a qualifier to any estimates, is that individuals of most species would not remain stationary throughout the accumulation period, so their dose accumulation would depend also on their motion.

For vibratory pile driving and non-explosive rock removal operations that produce continuous not impulsive sound, cSEL is calculated by summing (on a logarithmic scale) the SEL that represents 1 s of operation over the total number of operational seconds expected in 24 hours.

3. Model Parameters

3.1. Environmental Parameters

3.1.1. Bathymetry

Water depths throughout the modeled area were obtained from soundings collected by the U.S. Army Corps of Engineers in support of the New Bedford Harbor Superfund Project. These soundings were adjusted to match proposed dredged depth in the pile driving area. In areas where no soundings were available, data were obtained from STRM30+ (v7.0), a global topography and bathymetry grid with a resolution of 30 arc-seconds or about 2,300 × 6,000 ft (700 × 1,800 m) at the studied latitude (Rodriguez et al. 2005).

Bathymetry for a 10 × 12 miles (16 × 19 km) area, including waters from the Acushet River to Buzzards Bay, was re-gridded by minimum curvature gridding onto a Universal Transverse Mercator (UTM) Zone 19 projection with a horizontal resolution of 6.6 × 6.6 ft (2 × 2 m). Note that all maps presented in this report were projected onto the horizontal datum NAD 1983 U.S. State Plane Massachusetts Mainland Zone 19 (feet).

3.1.2. Geoacoustics

MONM assumes a single geoacoustic profile of the seafloor for the entire model area. The acoustic properties required by MONM are:

- sediment density,
- compressional-wave (or P-wave) sound speed,
- P-wave attenuation in decibels per wavelength,
- shear-wave (or S-wave) speed, and
- S-wave attenuation, in decibels per wavelength.

The geological stratification in New Bedford Harbor was based on boring logs provided by Apex. In general, dark grey sand with some grey to black organic silt was found down to 10–35 ft below the mudline. Based on the available data, this layer was averaged to 21 ft below the mudline for modeling purposes. Throughout the harbor, fractured grey granite bedrock (gneiss) is found directly below the silty sand layer. Seismic refraction data collected by Northeast Geophysical Services in March 2011 provided estimates of P-wave sound speed in this gneiss layer.

The other necessary acoustic properties were estimated from the geological stratification and sound speed data provided by Apex and values from analysis of similar material by Hamilton (1980), Ellis and Hughes (1989), and Barton (2007). Table 3 presented the geoacoustic profile used in this study.

Table 3. Estimated geoacoustic profile for Sites 1 and 2. Within each sediment layer, parameters vary linearly within the stated range.

Depth below seafloor (ft)	Material	Density (g/cm^3)	P-wave speed (ft/s)	P-wave attenuation (dB/λ)	S-wave speed (ft/s)	S-wave attenuation (dB/λ)
0-21	Sand and some black organic silt	1.77-1.95	5,331-7,150	0.96-1.10	1180	4.8
21-27	Grey granite Gneiss	2.6	10,250-16,807	0.275		
≥ 27	Grey granite Gneiss	2.6	16,807	0.275		

3.1.3. Sound Speed Profile

The sound speed profiles for the modeled sites were derived from sound speed profile data provided by Apex (Figure 7). These profiles were verified against temperature and salinity profiles from the US Naval Oceanographic Office's *Generalized Digital Environmental Model V 3.0* (GDEM; Teague et al. 1990, Carnes 2009). GDEM provides ocean climatology of temperature and salinity for the world's oceans on a latitude-longitude grid with 0.25° resolution, with a temporal resolution of one month, based on global historical observations from the US Navy's Master Oceanographic Observation Data Set (MOODS). The climatology profiles include 78 fixed depth points, up to a maximum depth of 22,310 ft (6,800 m) (where the ocean is that deep), including 55 standard depths between 0 and 6,562 ft (2,000 m). The GDEM temperature-salinity profiles were converted to sound speed profiles according to the equations of Coppens (1981):

$$\begin{aligned} c(z,T,S,\phi) &= 1449.05 + 45.7t - 5.21t^2 - 0.23t^3 \\ &\quad + \left(1.333 - 0.126t + 0.009t^2\right)\left(S - 35\right) + \Delta \\ \Delta &= 16.3Z + 0.18Z^2 \\ Z &= \frac{z}{1000}\left(1 - 0.0026\cos\left(2\phi\right)\right) \\ t &= \frac{T}{10} \end{aligned} \tag{18}$$

where z is water depth (m), T is temperature (°C), S is salinity (psu), and ϕ is latitude (radians).

The same monthly variations were observed in both Apex and GDEM data. Since Apex data were sampled within the New Bedford Harbor, and GDEM data were only available within Buzzard Bay, Apex's sound speed profiles are used to provide a more accurate estimate of the sound speed at the South Terminal Project sites.

To provide precautionary estimates of distances to level thresholds, sound propagation was modeled for the month of September (yellow, Figure 7). The sound speed profile in fall becomes slightly upward refractive, which promotes sound propagation by reducing interactions with the seabed.

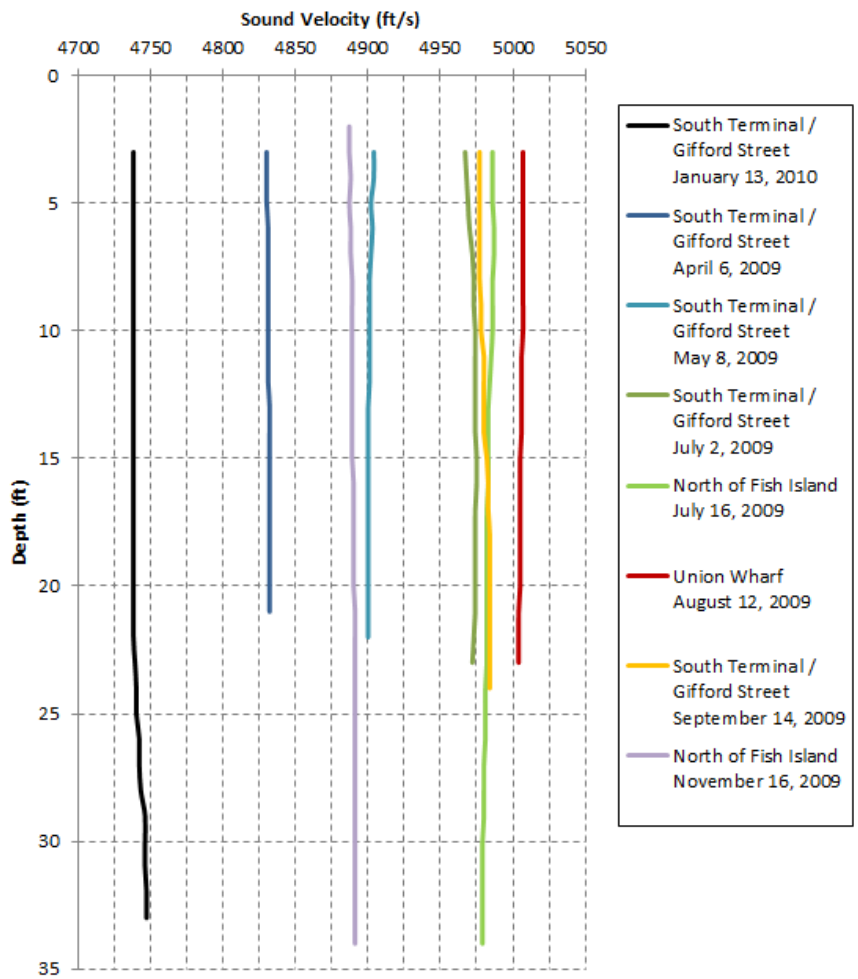

Figure 7. Sound speed profiles sampled at various locations and times of year within New Bedford Harbor, MA.

3.2. Geometry and Modeled Volume

The sound fields were modeled over New Bedford Harbor on an area about 13,123 × 23,950 ft (4.0 × 7.3 km), with a horizontal separation of 6.6 ft (2 m) between receiver points along the modeled radials. Sound fields were modeled with a horizontal angular resolution of $\Delta\theta = 2.5°$, for a total of $N = 144$ radial planes. The receiver depths span the entire water column over the modeled areas, from 1 to 164 ft (0.3 to 50 m), with step sizes that increased from 0.3 to 16.4 ft (0.1 to 5 m), with increasing depth.

4. Results

4.1. Source Levels

4.1.1. Pile Driving

Blackwell et al. (2007) provided received sound level spectra from vibratory pile driving. This spectrum revealed distinct peaks in the 1/3-octave bands centered at 16, 31.5, and 50 Hz, which are consistent with the vibration frequency of about 30 Hz. The spectrum was scaled to a broadband level equal to the maximum source level for vibratory pile driving a 24-inch (0.6 m) pile reported by Illingworth & Rodkin (2007): 185 dB re 1 $\mu Pa^2 \cdot s$.

Since the 24–36 inch diameter steel piles are to be set into pre-drilled holes, 1/3-octave bands source levels were also estimated for the drilling operation. JASCO recorded a Beetle (hammer) drill with a drill bit diameter of 24 inches passing through metamorphic rock (Mouy and Zykov 2009). The drill rig was installed on a temporary metal frame resting on the river bottom. This hammer-drilling operation and environment are expected to be representative of the activities proposed for the New Bedford terminal.

Figure 8 presents resultant source level spectra in 1/3-octave bands. Since the broadband levels are estimated higher for pile driving operations than for drilling operations, the spectrum for vibratory hammers was used in this study.

As the pile flexes under the action of the pile driver, its entire length excites pressure waves in the water, meaning that the pile is a distributed sound source. Because of losses from bottom and surface interactions, attenuation will be less for a source at mid-depth than for one near the seafloor or surface. The pile was approximated by a point source located at half the water depth. This positioning of the equivalent point source is estimated to result in precautionary distances to sound level thresholds.

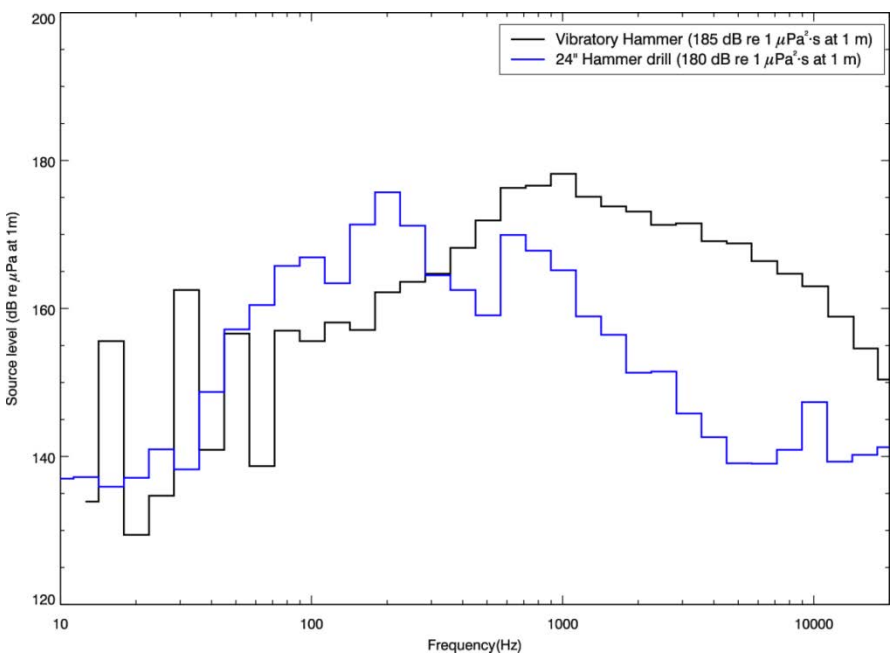

Figure 8. Estimated 1/3-octave band source level spectra for pile driving operations.

4.1.2. Rock Removal–Non-Explosive Methods

Since underwater spectrum representing hydraulic impact hammering (Hoe Ram) and drilling and fracturing of metamorphic rock were not found in the literature, a Beetle (hammer) drill with a drill bit diameter of 24 inches passing through metamorphic rock (Mouy and Zykov 2009), was used as proxy for the two types of activities.

A cutter-head may also be used to help loosen the sediments. The head can usually be steered using cables and winches or thrusters. Generally, cutter-head dredges do not have a propulsion system, but use *legs*, known as spuds, to swing between anchors, or may use service tugs. The major source of noise is generated by the impact and abrasion of the sediment passing through the cutter-head, suction pipe, and pump (Robinson et al. 2011).

Backhoe dredgers are relatively quiet compared to other dredges (CEDA 2011). The noise sources from backhoe dredging are the barge-installed power plant and scraping sounds as the bucket digs into hard sediment. Backhoe and bucket dredgers have a similar setup: a crane installed on a barge. The only difference being that the bucket is controlled through a steel wire cable instead of a rigid arm. Since noise measurements of a backhoe dredger were unavailable, clamshell bucket dredge measurements were used as proxy.

One dredging duty cycle for a clamshell bucket dredge involves the following events:

- Bucket striking the bottom,
- Bucket digging into the bottom/bucket closing,
- Winching up, and
- Dumping the material from the bucket.

Dickerson et al. (2011) identified that the noisiest event is the bucket striking the bottom. This acoustic event is very short compared to the length of a duty cycle (~1 min), and happens once per duty cycle. The source levels for other events are at least 6 dB lower. Table 4 presents the specification for the cutter-head and clamshell bucket dredges considered in this study. Figure 9 presents the 1/3-octave band source level spectra for cutter-head dredges, clamshell bucket dredges, and a 24-inch hammer drill.

Table 4. Dredges Specifications.

Dredge Name	Type	Length × breath × draft (ft)	Capacity	Pump power (kW)	Dredging depth (ft)	Estimated rms SPL broadband level (dB re 1 µPa @ 1 m)	Reference
JFJ de Nul	Cutter-head suction dredge using thruster to move cutter-head	408 × 91 × 21	unknown	Cutter drive: 6000 Submerged dredge pump on cutter ladder: 3800 Inboard dredge pumps: 2 x 6000 Propulsion: 2 x 3800 Total installed power: 27 190	19 (min) 115 (max)	179.6	Hannay et al. 2004 and http://www.sakhalinenergy.com/en/documents/doc_33_cea_tbl4-7.pdf
Aquarius	Self-propelled Cutter-head suction dredge using thrusters to move cutter-head	351 × 62 × 16	unknown	unknown	82 (max)	185.5	Malme et al. 1989
Columbia	Cutter-head suction dredge using winch to move cutter-head	160 × 44 × 7	unknown	Cutter power: 375 Total power: 3954 Pipe Diameter: 2 ft	59 (max)	181.8	McHugh et al. 2007
Beaver MacKenzie	Cutter-head suction dredge using winch to move cutter-head	284 × 51 × 13	Gross tonnage: 2148.5 t	Ladder: 1119 (1500 hp) Discharge: 1268 (1700 hp) jet pump: 1119 (1500 hp) Pipe Diameter: 2.8 ft	148 (max)	172.1	Malme et al. 1989
Viking	Clamshell bucket dredge	260 × 66 × 6	Maximum lift : 136 t	unknown	unknown	169.5	Dickerson et al. 2001
Argilopotes	Clamshell bucket dredge	unknown	unknown	unknown	unknown	167.6	Miles et al. 1987

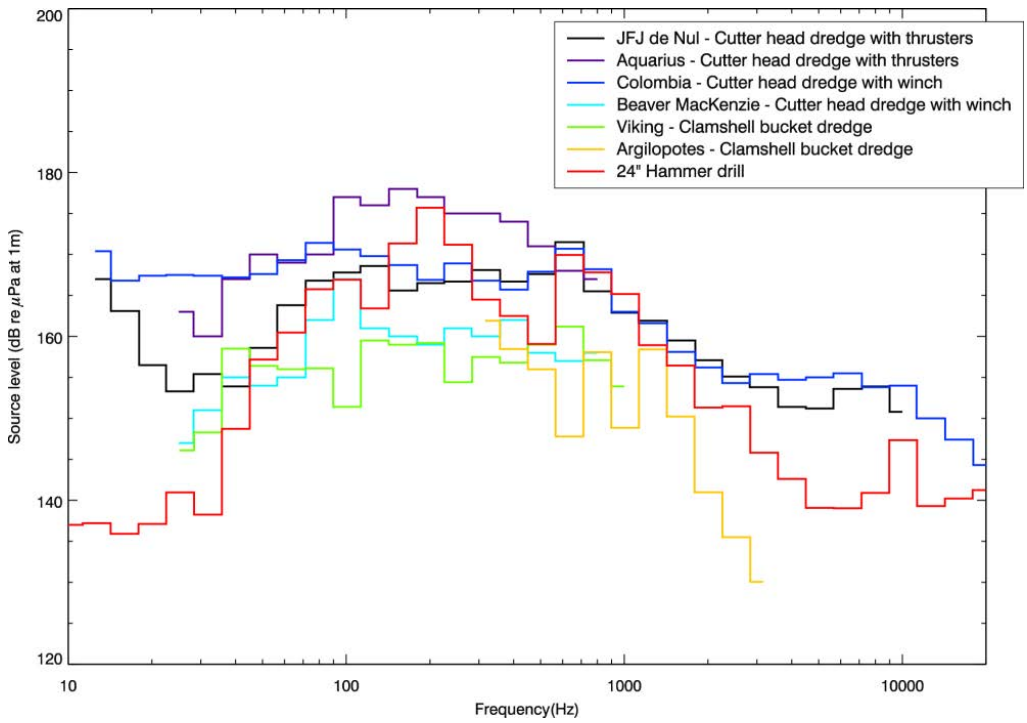

Figure 9. Estimated 1/3-octave band source level spectra for cutter-head dredges, clamshell bucket dredges, and a 24-inch hammer drill.

Sound levels from the cutter-head dredge Aquarius were used in this study, since they represents the highest broadband source levels (185.5 dB re 1 µPa @ 1 m). As the available spectrum for Aquarius does not include frequencies above 800 Hz, source levels at higher frequencies were estimated using the highest values in each 1/3-octave band between the cutter-head dredges JFJ de Nul and Colombia.

Because losses from bottom and surface interactions will be less for a source at mid-depth than for one near the seafloor or surface, the sound of non-explosive rock removal activities was approximated by a point source located at half the water depth. This positioning of the equivalent point source is estimated to produce results in precautionary distances to level thresholds.

4.1.3. Rock Removal–Explosives

The use of explosives may be required to facilitate rock removal. Bedrock blasting will likely be performed by drilling small diameter boreholes (~4 inch) into bedrock for several feet (6–10 ft) with a maximum charge weight of 50 lbs. At the time of modeling, the contractor had not been chosen, therefore important specification data for the blasting operations, such as the type of explosive, were not available. Substitute parameters were selected based on JASCO's previous experience with blasting modeling. Pentolite was selected as the explosive type for blast modeling. The explosive specific coefficients of Pentolite for shockwave prediction are provided in Table 5.

Table 5. Explosive specific coefficients used in Equations 16 and 17 (Dzwilewski and Fenton 2003).

Explosive	Pentolite
K_P	56.5
α_P	1.14
K_I	5.73
α_I	0.91

The peak pressure and impulse of the shock wave from explosive rock removal operation were predicted with UnderWater Calculator (Dzwilewski and Fenton 2003). Coupling efficiency of a charge placed inside bedrock is expected to be similar to the one inside a steel pipe with wall thickness of 1 inch. The estimated coupling efficiency varied with the charge size from 35.6% for a 10-lbs charge to 46.4% for a 100-lbs charge.

Equations 16 and 17 calculate the peak pressure and impulse values of the shockwave from a blast. The calculations were done for the distances as far as 4500 ft from the blast point. Since the charge weight has not been determined, several scenarios were considered with different charge sizes: 10, 20, 30, and 50 lbs. Scenarios with a charge inside a pipe were considered to provide estimates of a buried charge. The considered method for shockwave modeling does not take into account the variation of the bathymetry around the rock removal site.

4.2. Sound Fields

It is important to note that several assumptions were made to estimate precautionary distances to sound level thresholds. In addition to the assumptions detailed in Sections 2, 3, and 4.1, the water column was assumed free of obstructions like construction barges or other vessels that could act as partial noise barriers, depending on their draft. The underwater sound fields predicted by the propagation model were also sampled such that the received sound level at each point in the horizontal plane was taken to be the maximum value over all modeled depths for that point (see Section 2.4.1).

The predicted distances to specific sound level thresholds were computed from the maximum-over-depth sound fields. Two distances, relative to the source, are reported for sound levels representing the selected impact criteria: (1) R_{max}, the maximum range at which the given sound level was encountered in the modeled sound field; and (2) $R_{95\%}$, the maximum range at which the given sound level was encountered after exclusion of the 5% farthest such points. This definition is meaningful in terms of impact on marine life, because, regardless of the geometric shape of the noise footprint for a given sound level threshold, $R_{95\%}$ is the predicted range encompassing at least 95% of animals of a uniformly distributed population would be exposed to sound at or above that level.

The model results are presented as contour maps of maximum-over-depth rms SPL in 10 dB steps, and to maximum-over-depth peak SPL, cSEL, and rms SPL, or peak pressure and impulse level thresholds. Distances (R_{max} and $R_{95\%}$) to specified threshold are recorded in the legend of the contour maps for pile driving and non-explosive rock removal operations, and tabulated for rock removal operations using explosives.

4.2.1. Pile Driving

Apex estimates that each pile will to be driven into place in about 10 min using a vibratory hammer. Cumulative SEL was calculated assuming 10 min of vibratory hammer pile driving operation for each of the 16 piles to be driven in a 24-hour period. Thus, cSELs presented here assume 9600 s of operation in 24 hours. Peak SPL for vibratory pile driving is not expected to reach 206 dB re 1 µPa.

Figure 10 presents a contour map of the modeled rms SPL for pile driving operation with vibratory hammer. Figure 11 presents a contour map of the modeled sound level thresholds for that type operation.

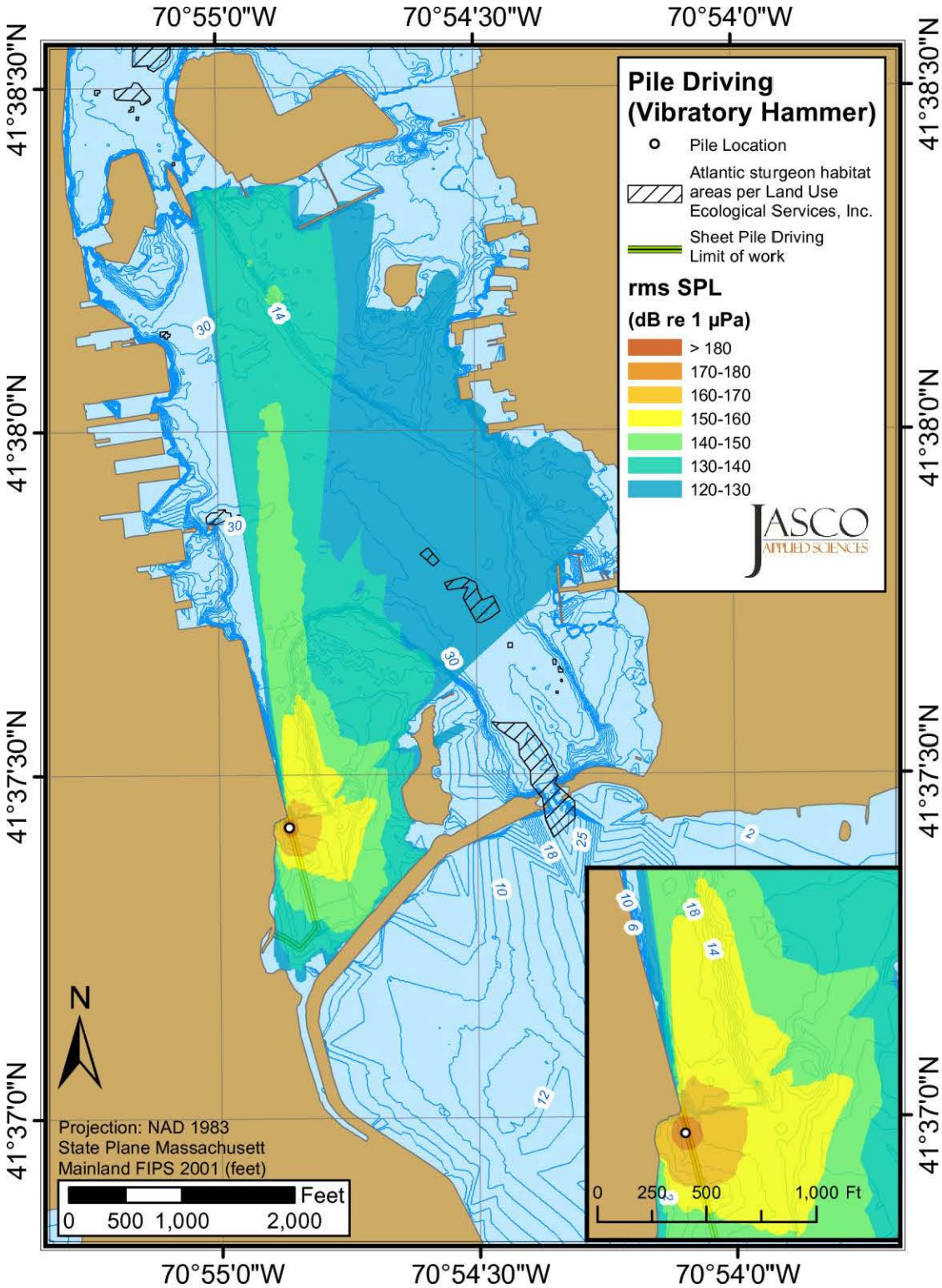

Figure 10. Pile driving with a vibratory hammer at Site 2: Received maximum-over-depth root-mean-square (rms) sound pressure levels (SPLs). Blue contours indicate water depth in feet.

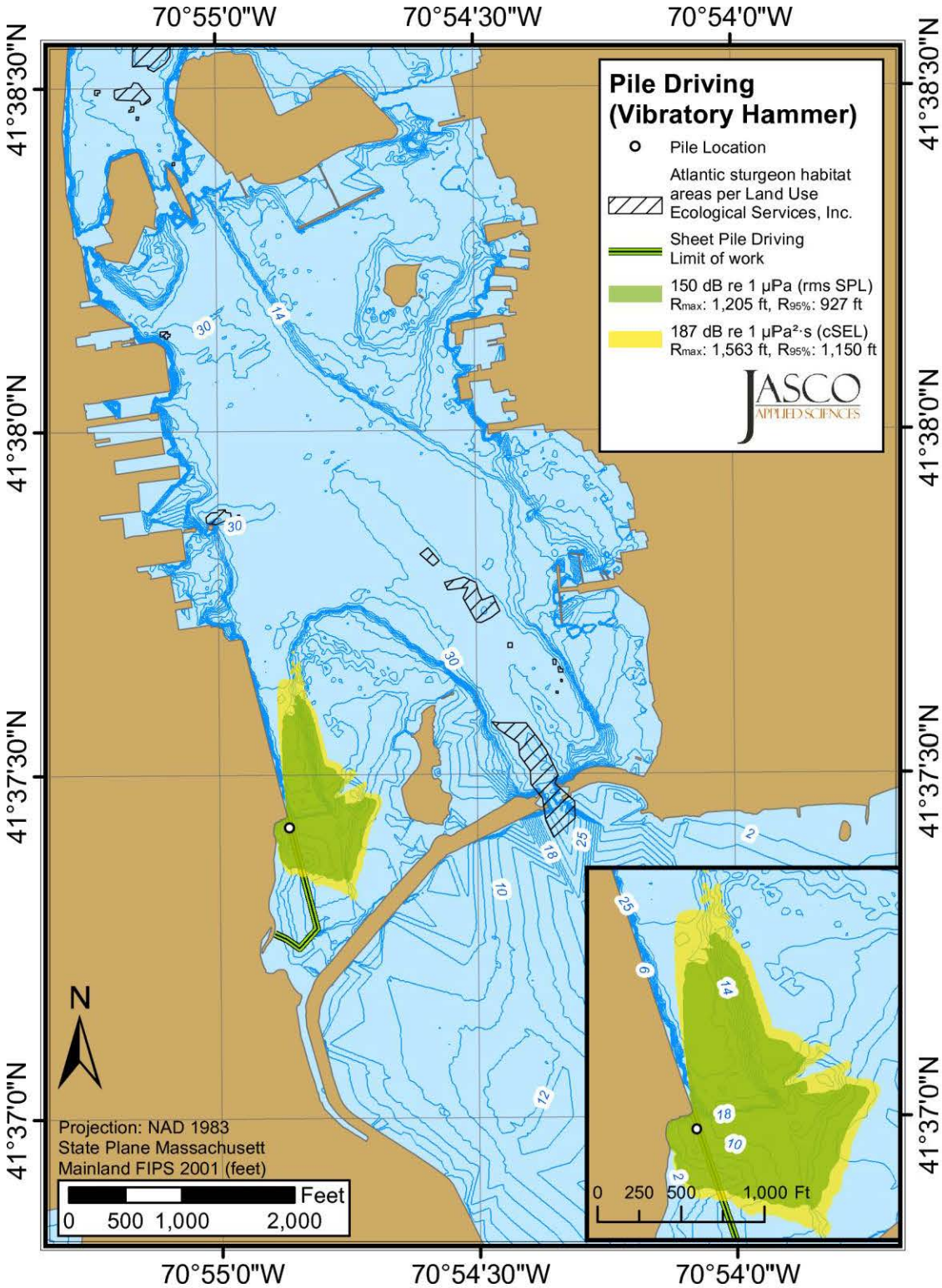

Figure 11. Pile driving with a vibratory hammer at Site 2: Received maximum-over-depth sound level thresholds. Blue contours indicate water depth in feet.

4.2.2. Rock Removal–Non-Explosive Methods

Apex estimates 4 hr of non-explosive rock removal operation. Thus, cSELs presented here assume 14 400 s of cutter-head dredge operation in 24 hours. Peak SPL for vibratory pile driving is not expected to reach 206 dB re 1 μPa.

Figures 12 and 14 present contour maps of the modeled rms SPL for non-explosive rock removal (using a cutter-head dredge), while Figures 13 and 15 present contour maps of the modeled sound level thresholds for same type of operation.

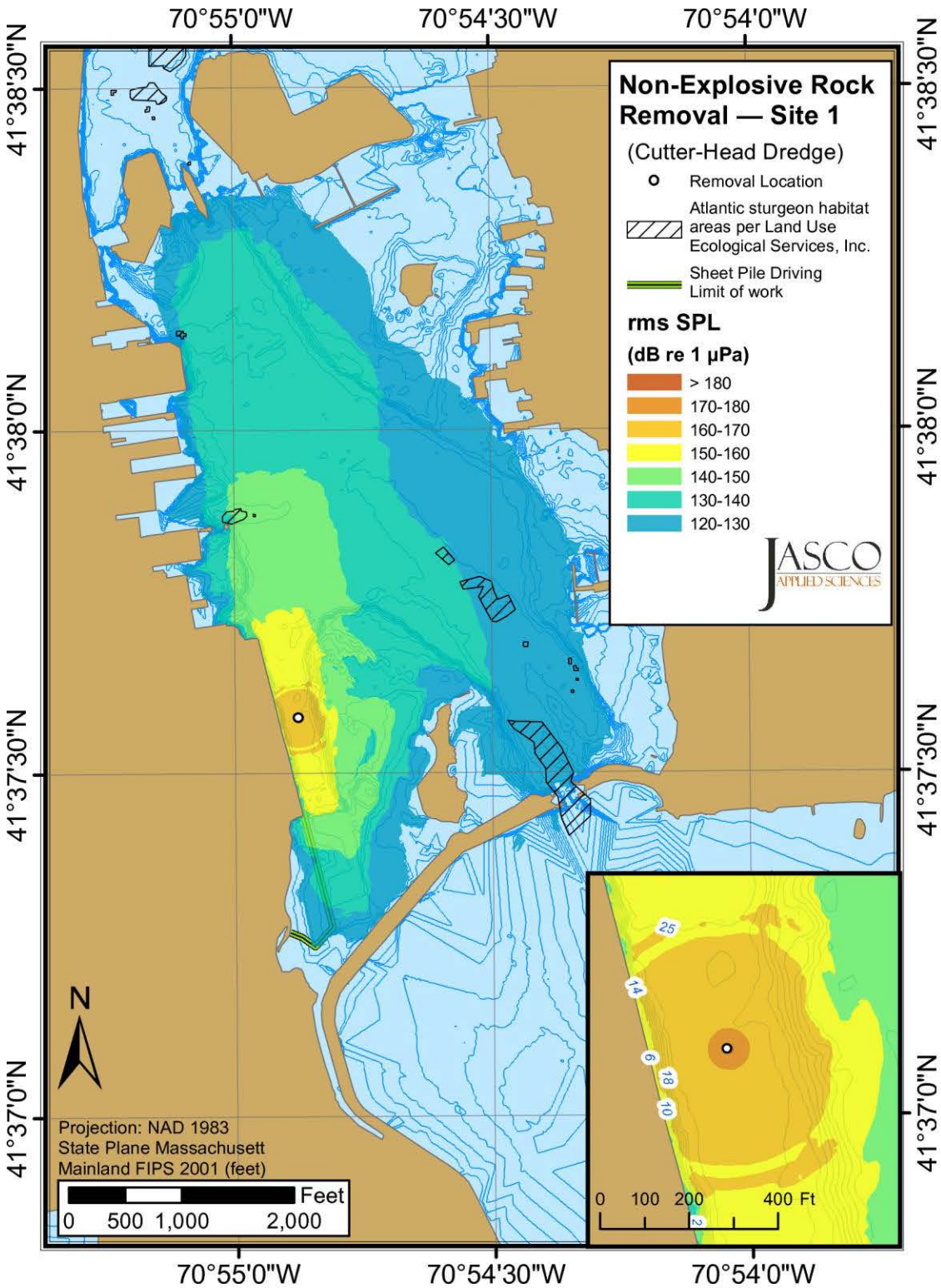

Figure 12. Non-explosive rock removal at Site 1: Received maximum-over-depth root-mean-square (rms) sound pressure levels (SPLs). Blue contours indicate water depth in feet.

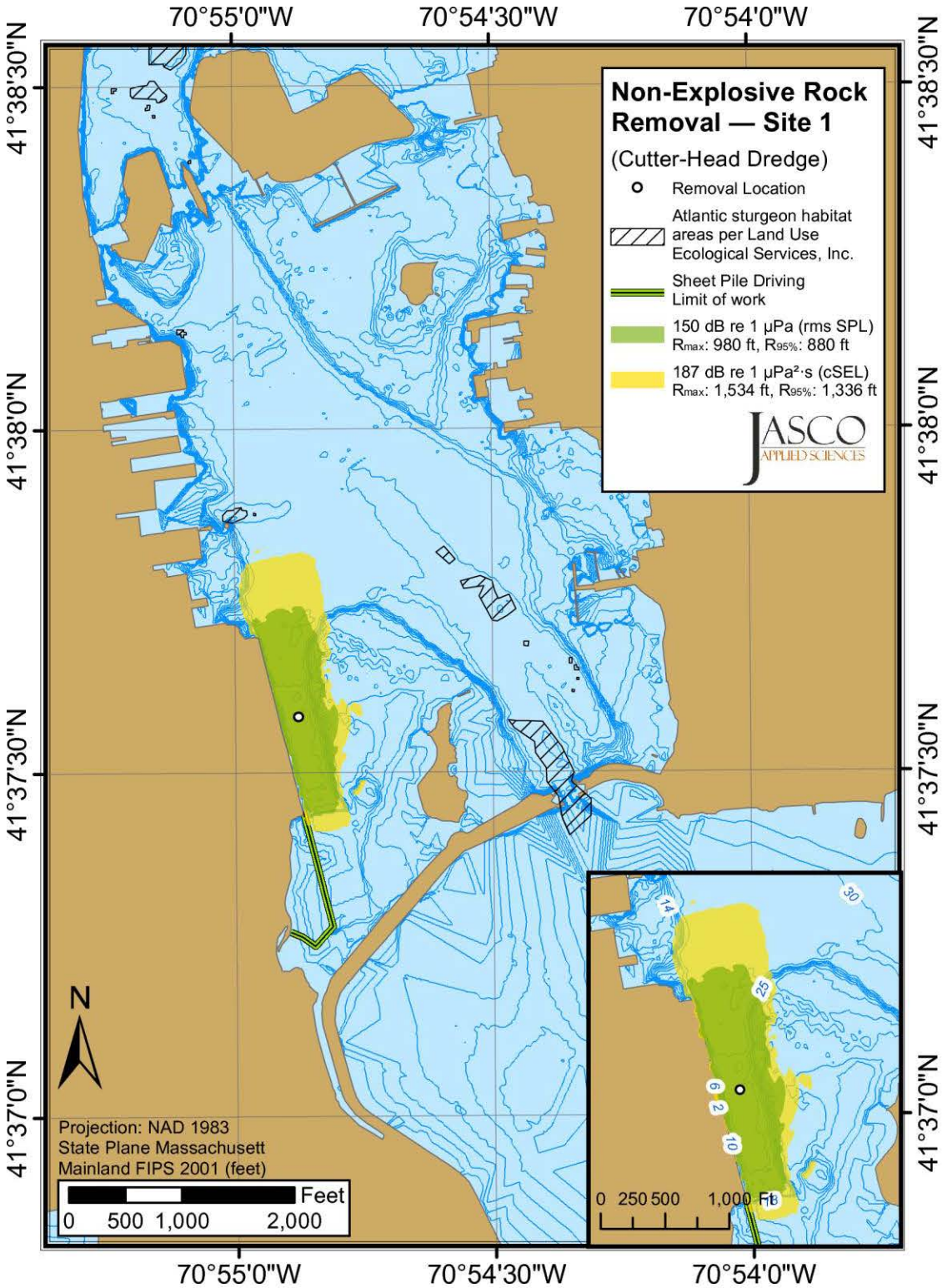

Figure 13. Non-explosive rock removal at Site 1: Received maximum-over-depth sound level thresholds. Blue contours indicate water depth in feet.

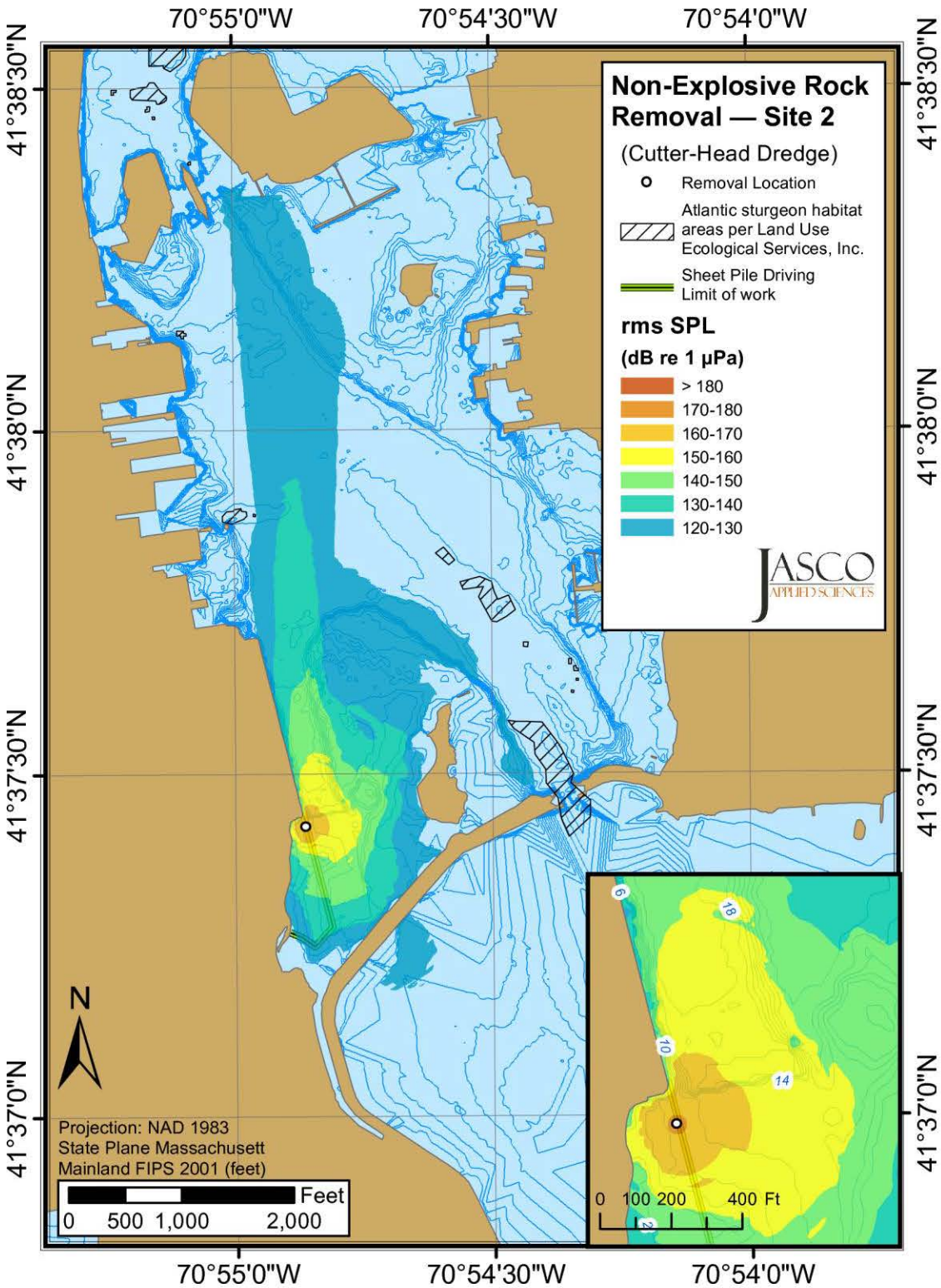

Figure 14. Non-explosive rock removal at Site 2: Received maximum-over-depth root-mean-square (rms) sound pressure levels (SPLs). Blue contours indicate water depth in feet.

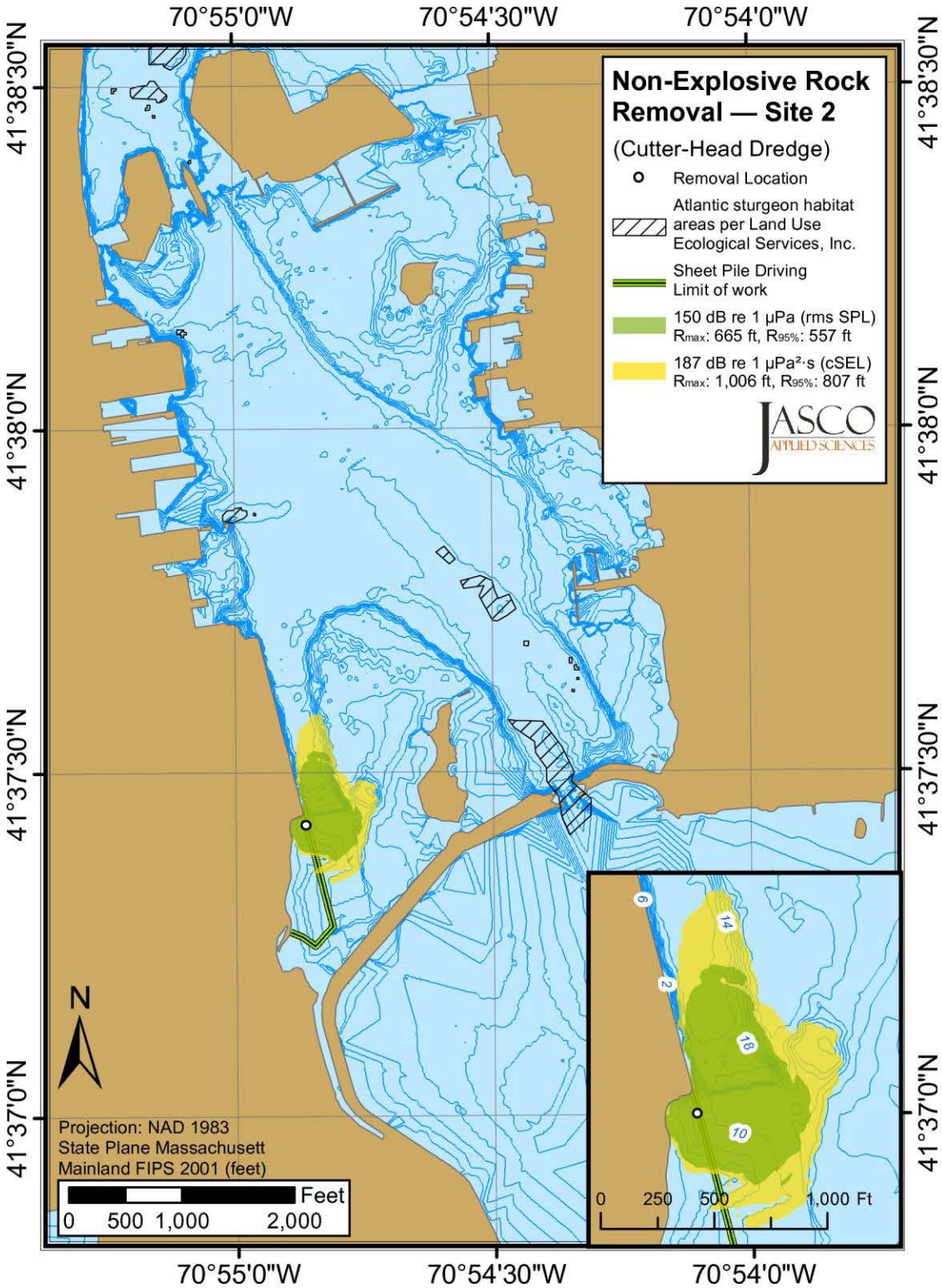

Figure 15. Non-explosive rock removal at Site 2: Received maximum-over-depth sound level thresholds. Blue contours indicate water depth in feet.

4.2.3. Rock Removal–Explosives

The estimated functions of peak pressure and impulse versus distance are shown in Figures 16 and 17, respectively. The functions for four different charge weights are provided for buried explosives.

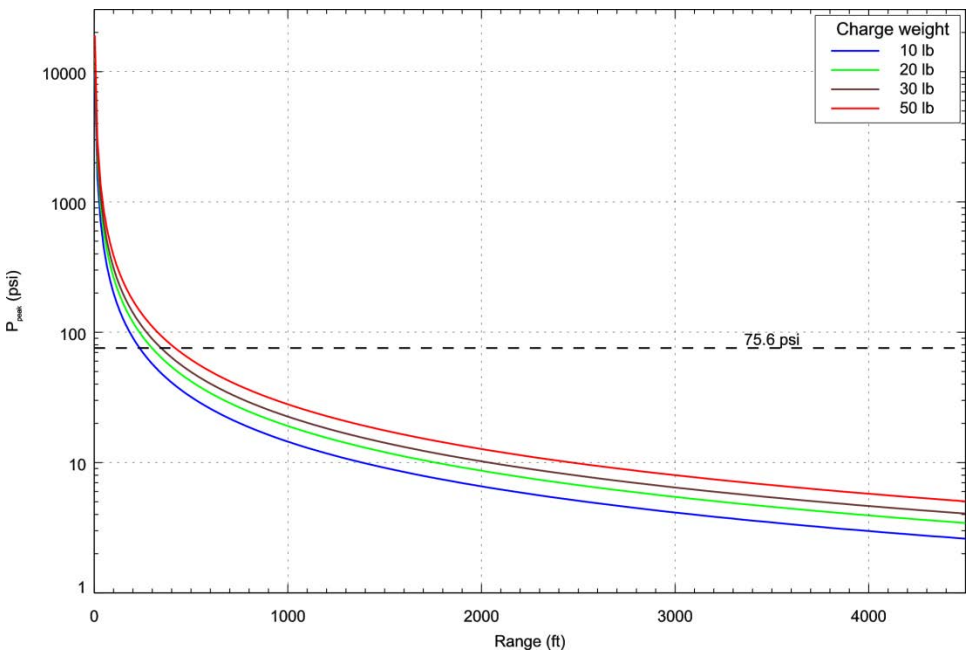

Figure 16. Predicted peak pressure of the shockwave from buried Pentolite charges of selected weight. The 75.6 psi safety criteria threshold is shown.

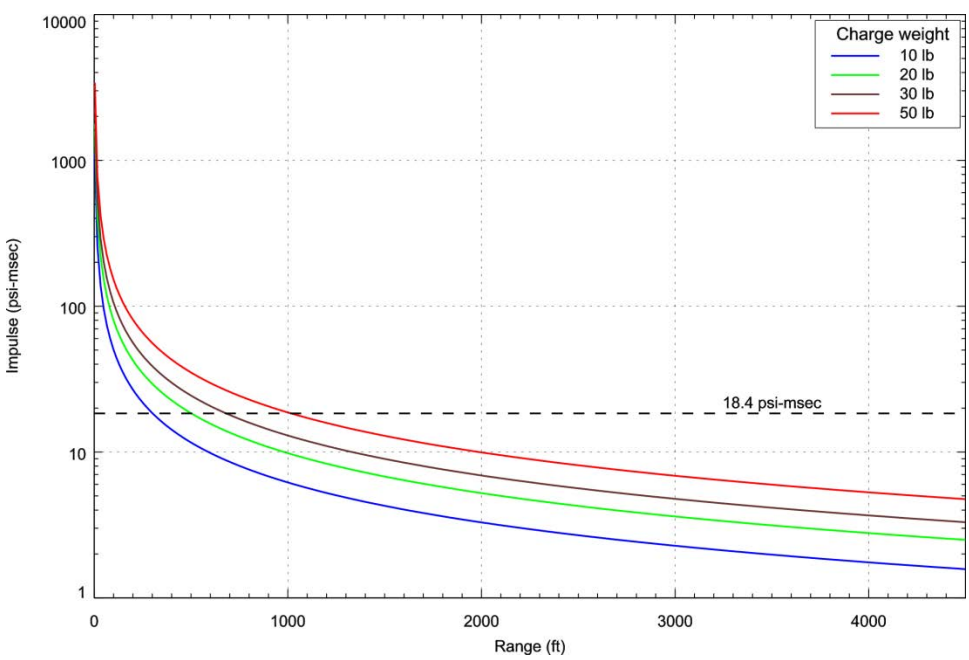

Figure 17. Predicted impulse of the shockwave from buried Pentolite charges of selected weight. The 18.4 psi-msec safety criteria threshold is shown.

Table 6 provides predicted off-set ranges based on peak pressure (75.6 psi) and impulse (18.4 psi-msec) metrics of the unmitigated and mitigated (bubble curtain) blast shock wave. The mitigation effect of a bubble curtain is considered to provide a 12 dB reduction in pressure of the shockwave. Figures 18–21 present in contour map format the predicted off-set ranges for charges from 10 to 50 lbs.

Table 6. Predicted off-set ranges (ft) based on peak pressure (75.6 psi) and impulse (18.4 psi-msec) threshold criteria. With and without mitigation system (-12 dB). The maximums of two off-sets are provided.

Charge Weight (lbs)	Unmitigated			Mitigated		
	P_{peak}	*Impulse*	*Max*	P_{peak}	*Impulse*	*Max*
10	235	302	302	14	66	66
20	299	502	502	23	110	110
30	346	681	681	32	149	149
50	418	1017	1017	47	223	223

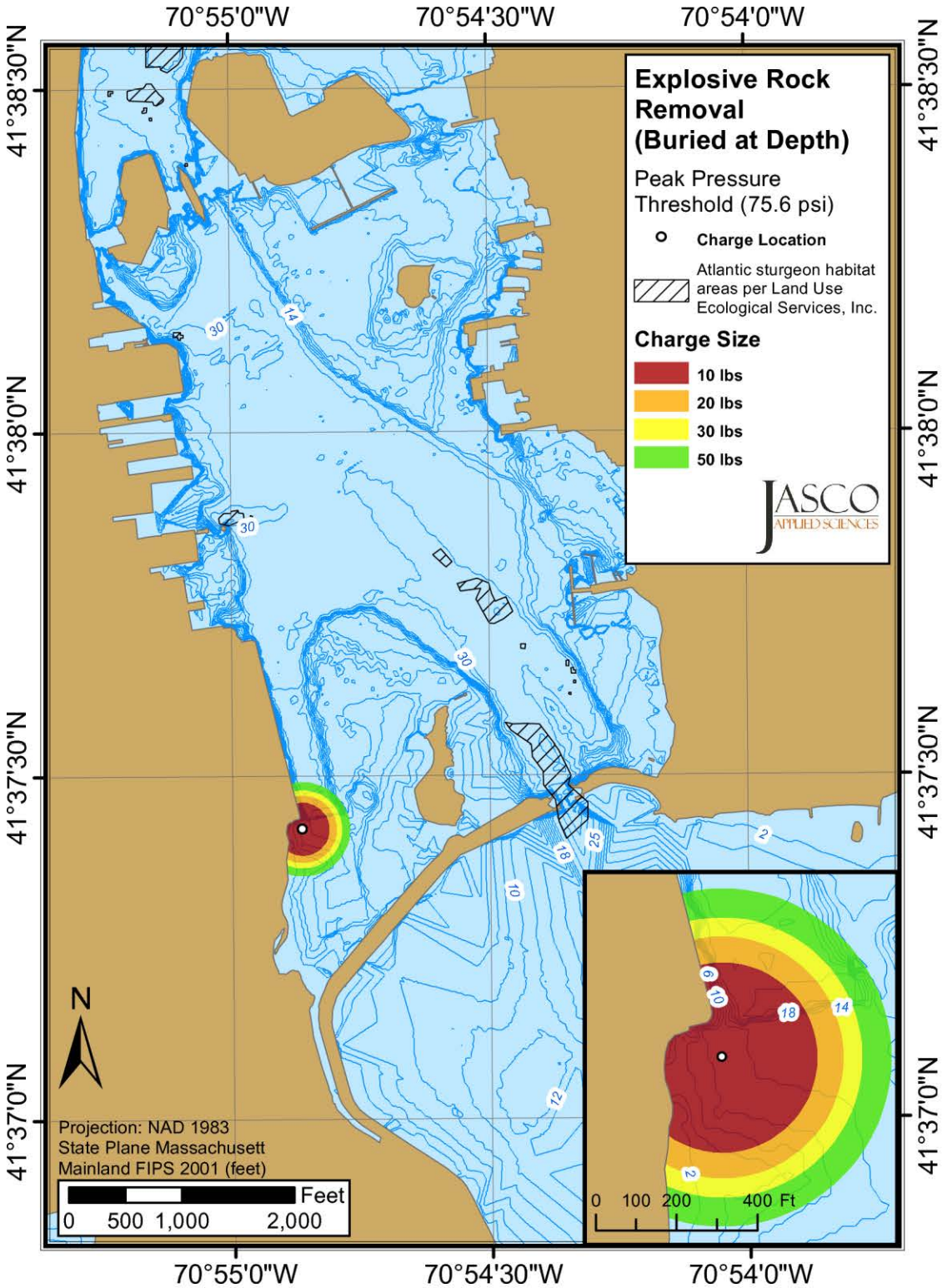

Figure 18. Explosive charge at Site 2: Peak pressure threshold of 75.6 psi for explosive charges between 10 and 50 lbs. Blue contours indicate water depth in feet.

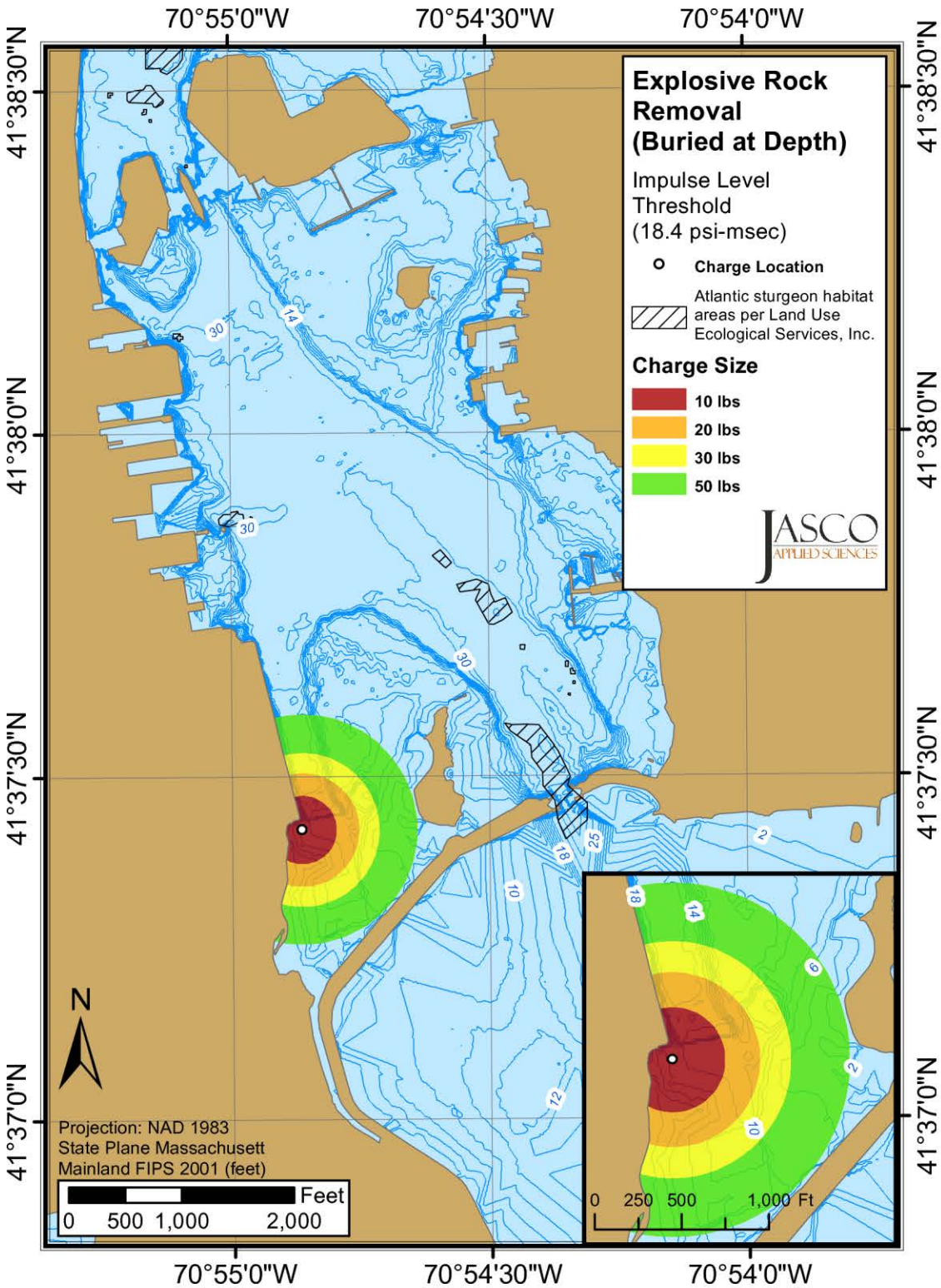

Figure 19. Explosive charge at Site 2: Impulse level threshold of 18.4 psi·msec for explosive charges between 10 and 50 lbs. Blue contours indicate water depth in feet.

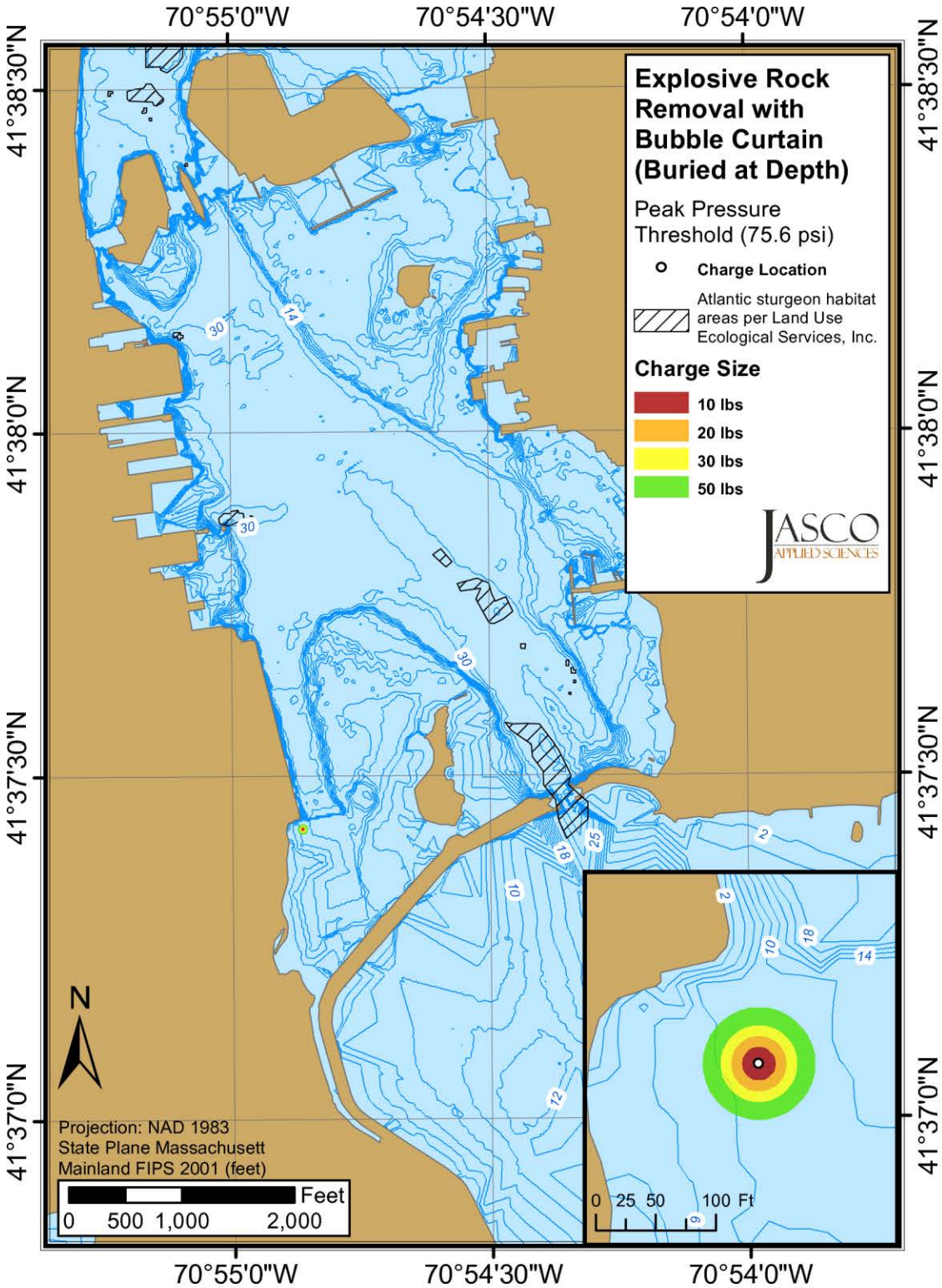

Figure 20. Explosive charge with bubble curtain at Site 2: Peak pressure threshold of 75.6 psi for explosive charges between 10 and 50 lbs. Blue contours indicate water depth in feet.

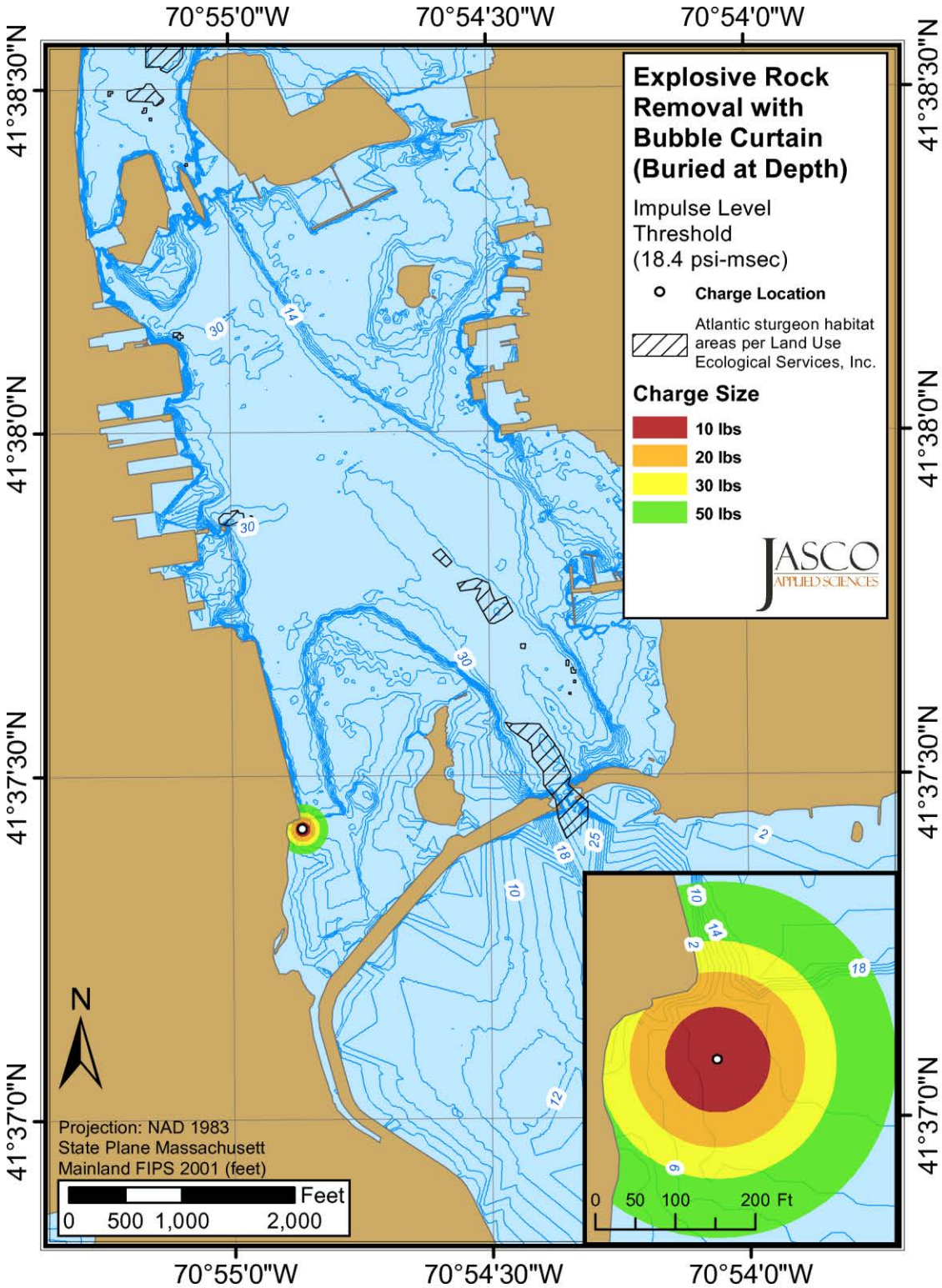

Figure 21. Explosive charge with bubble curtain at Site 2: Impulse level threshold of 18.4 psi·msec for explosive charges between 10 and 50 lbs. Blue contours indicate water depth in feet.

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Errata

For *Underwater Acoustic Modeling of Construction Activities: Marine Commerce South Terminal in New Bedford, MA*, version 3.0

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Date: 22 March 2013

Erratum in Section 2.3. Air Bubble Curtain

Paragraph 2 of Section 2.3 (p 13) currently reads:

> The mitigation effect of the bubble curtain measured at different depths varied between 9.5 and 19.9 dB (Nützel 2008). This study assumes a bubble curtain will have a 12 dB mitigation effect on the shockwave from a blast.

It should read:

> The average mitigation effect of the four bubble curtain setups measured at different depths varied between 11.3 and 17.6 dB (Nützel 2008). This study assumes a bubble curtain will have a 12 dB mitigation effect on the shockwave from a blast. The 12 dB value was selected as the 90th percentile of the 16 attenuation values provided by Nützel (2008).

ATTACHMENT C

Logging the mechanical character of rock

539.5 : 552.1

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Synopsis
To make the best use of rock core, the mechanical character of the rock should be evaluated concurrently with conventional geological observations. The advent of simple techniques, such as the point load 'nutcracker' test, makes field logging of mechanical properties competitive with sampling and testing in the laboratory.

All too often, rock core, an expensive item on any site exploration budget, is underutilized owing to inadequate logging. This state of affairs can result from a division of interest between stratigraphic and mineral prospecting, on the one hand, and geotechnical site investigation, on the other. Duplication of effort can be avoided by planning the logging to ensure that both geological and geotechnical data are obtained in the one operation.

Core storage involves further expense. The retention of core for observation and testing at a later date, owing to multiple handling and drying out, results in rock deterioration. It is suggested that by the use of careful geological and geotechnical index logging to obtain the maximum of information at the drill site, the majority of core storage can be avoided. A log of this sort, supplemented by selective sampling of important mineralogical and geotechnical horizons with the samples packaged to preserve their *in situ* properties, should be quite adequate for most purposes. To be sufficiently reliable this logging must be supervised by a geologist or geotechnical engineer permanently on site. In the United Kingdom the present cost of core boxes to house the daily output of core is often more than the daily earnings of the person who logs it. When the cost of adequate storage and the need for the core to be examined conventionally are considered, the advantages of mechanical logging become apparent.

At present mechanical tests are usually detached from the geological logging, and, if complex or time-consuming, they may require a laboratory. Simple field techniques can, however, be used to make test data available at the time of logging—some are described below. Various applications of these logs to rock engineering problems are then discussed.

Mechanical indices

Geotechnical core logs contain both mechanical and geological information. As an expanded geological description soon becomes too cumbersome for practical use, it is better to leave the geological log in simple form and to present mechanical information separately—in the form of 'mechanical index logs'. An index is a numerical guide to rock character, based on a simple test or observation. Continuous records of indices are called 'index logs'. Geological character may be inferred from indices such as grain size or quartz content; mechanical character from indices such as strength and fracture spacing.

Fig. 1 employs mechanical index logs obtained from rock core, but information can also be obtained from within the borehole. Packer pumping tests, for example, are frequently useful to provide permeability logs for grout take evaluation and drainage design. Downhole sonic, electric and gamma logs can supplement the information on mechanical properties, or they can assist in stratigraphic correlation. The Menard pressuremeter and the 'Standard Penetration Test' also provide logs that give a useful indication of rock quality.

One index on its own can be misleading, and several are usually combined to give a clearer impression of rock character. There are many alternatives, and for economic reasons the logging must be selected from the most effective indices. If simple techniques are chosen, more indices can be incorporated in the logging programme. A stage is reached, however, when the extra information obtained from a further test is not worth the added complexity and effort. Mechanical indices, besides being simple, must be relevant to the engineering performance of rock, as well as accurate and repeatable. They should be considered as part of a complete index testing programme rather than on their individual merits alone.

Index tests can be considered in two categories—'basic' and 'supplementary'. The 'basic' tests and observations are those required to form the basis of an engineering rock classification applicable to the majority of rock engineering problems. A geological log, a fracture spacing log and a strength log have been selected for this purpose, for reasons that are discussed later. Basic logs of a standard type are required if experience gained at one engineering site or in one suite of rocks is to be put to good use at a later date.

Supplementary tests may be used to add greater depth to the rock description. Tests are chosen to suit both the expected engineering problems and the rock types to be encountered—for example, to provide engineering design data in critical areas of the rock mass, e.g. deformability measurements in the immediate vicinity of a foundation or shear strength testing of a critical horizon in a slope; to provide supplementary information for specific problems, e.g. soundness tests on aggregate or durability tests on rock fill; for economic evaluation of minerals, e.g. the ash content of coal seams or variations of grade in an orebody; and to assist in stratigraphic correlation where no obvious markers exist, e.g. microfossil counts or acid residues from chalk.

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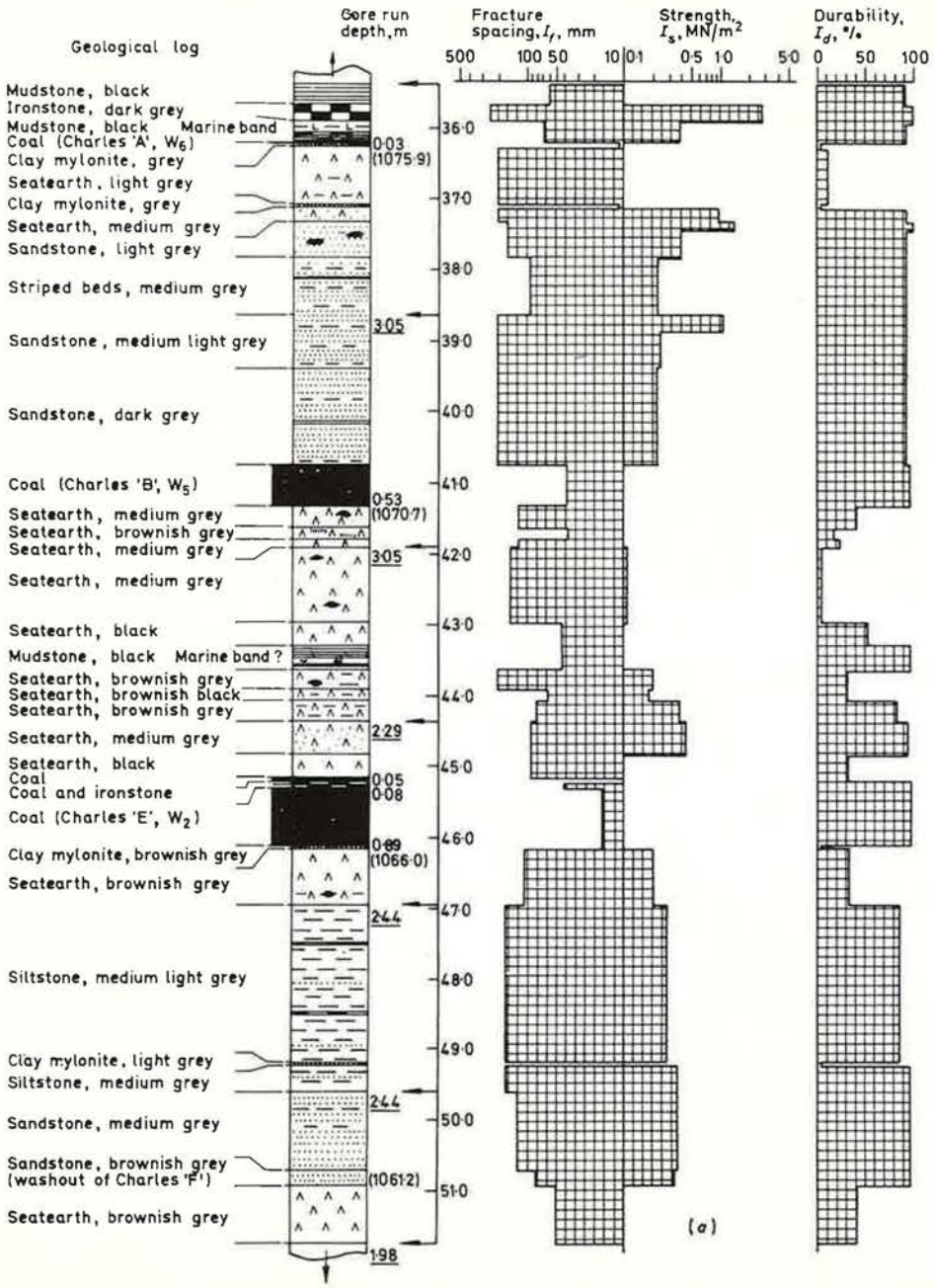

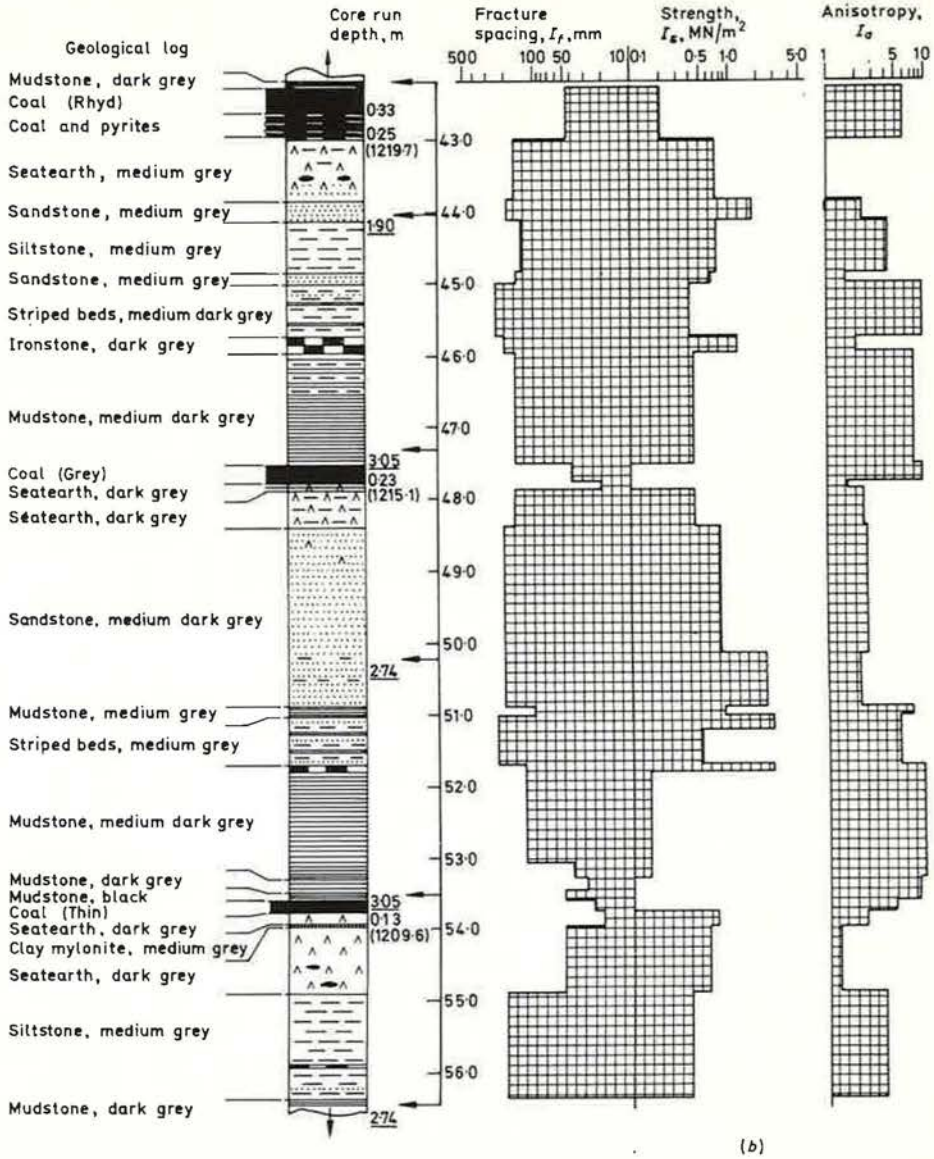

Fig. 1 Geotechnical logs of core from Productive Coal Measures rocks in England (*a*) and Wales (*b*)

Supplementary index data should, if possible, be presented in the form of a continuous log. Tests may be complex and expensive, and should consequently be restricted to critical areas of the rock mass. Supplementary testing should also be planned in advance, and, if it cannot be done in the field, sampling and careful packaging should be allowed for within the logging programme.

Core logging procedure

The basic tests and observations are made in the field, immediately after the rock has been extruded from the core barrel. Rock should always be inspected and tested at *in situ* water contents and should not be disrupted by handling or storage. On initial inspection of the core, units are chosen that have apparent mechanical and lithological homogeneity. They are selected by eye after probing with a penknife—not a hammer—each unit being numbered and marked to show clearly its boundaries. The geological, fracture and strength logs are then produced in sequence, though some cross reference may be required—for example, geological description might need closer examination after rock has been split in strength testing. Sufficient index tests or observations are carried out on each unit of core to give reasonable estimates for the mechanical indices. The basic logs are then examined to select sites for supplementary testing. If necessary, samples are selected, packaged and labelled for laboratory testing.

The logs considered together should give an immediate guide to the variation in rock quality with depth, and should also contain sufficient stratigraphic and mineralogical information for prospecting requirements. Rock properties may be computer-coded to allow use of automated techniques for data processing and map preparation.

Basic logging

The geological log

The geological log is principally designed for its role in mineralogical and stratigraphic interpretation, though its value as a guide to engineering performance should not be neglected.

There is general agreement that unqualified rock names are inadequate for engineering and stratigraphic purposes alike. Granite, for example, may have properties anywhere between those of a strong rock and a soil. The mechanical index logs, for the most part, take care of mechanical qualification of the rock name (e.g. Granite, low fracture spacing, high strength). Hence, some simplification of the rock description in the geological log is then possible.

The log is essentially qualitative, and must include the rock name, the state of weathering, structure (including a description of discontinuities), colour and grain size or rock texture. Extra information of structural or stratigraphic value, such as specific horizon names, dip, fossil and mineral bands and certain sedimentary structures, should also be included, but not so as to disrupt the order above. In mining the rock name is usually placed first in the description, particularly when logs are to be used for much structural interpretation. Important properties, such as colour and grain size, should be standardized to avoid subjective errors.[1,2] In most situations simple descriptions are adequate.[3]

The fracture spacing log

The discontinuous nature of a rock mass plays an obvious part in deciding such mechanical properties as deformation modulus, strength and permeability. Faults, joints and bedding planes are important in that they affect the degree of freedom available for displacements or fluid movements within a rock mass. Significant features of these discontinuities are their spacing, orientation, persistence, irregularity, tightness and infilling. Of these, spacing is thought to be particularly relevant to the engineering properties of rock. Other things being equal, a strong mass consists of large blocks with few fractures; a weaker rock mass has smaller blocks grading ultimately into soil materials. Spacing is also more easily measured than most other fracture properties.

Of the several attempts to quantify fracture or joint spacing,[4] one of the better known, that of rock quality designation (RQD)[5] is based on a modified core recovery system with NX or larger barrels. Lengths of core stick longer than 10 cm are counted as a percentage of the total drill run. The engineering quality of the rock is then graded in terms ranging from very poor to excellent. The authors prefer to record a direct measure of fracture spacing by use of a *fracture spacing index*, l_f, which refers to the average size of cored material within a recognizable geological unit.

When few fractures traverse the core, the index is the unit length divided by the number of fractures within the unit. If the core is very broken, the index is the average diameter of a number of separate rock fragments. The orientation of fractures must be taken into account. Fractures perpendicular to the direction of coring will be more frequently intersected and may bias the observations. Ideally, inclined boreholes are needed for an accurate estimation of the fracture spacing index, but for many purposes estimation from a single borehole may be quite sufficient. Cores are examined immediately on removal from the core barrel—this excludes drying cracks from the log, and makes it easier to recognize those fractures which result from drilling and are not to be included.

The fracture logs of Fig. 1 are plotted on a logarithmic scale because rock, like soil, is most conveniently subdivided logarithmically for classification. More accurate observations are therefore required of small fragments than of large blocks to avoid misclassification, but fewer large blocks are available for observation, so care must be taken since a single artificial fracture may affect the results.

The strength log

Traditionally, rock strength is either estimated in the field by use of a hammer or in the laboratory with sophisticated apparatus. The former method is at best qualitative, whereas the latter requires careful specimen preparation. There is an obvious need for a device to test, quickly and reliably, unprepared core in the field.

A portable point load tester has been developed at Imperial College, London, as an aid to core logging (Fig. 2). The apparatus consists of a small hydraulic

Fig. 2 Portable point load tester used to obtain a strength index, I_s

pump and ram, with a loading frame of maximum rigidity easily adjustable to test core of different sizes. Core is loaded between pointed platens of standard dimensions. A quick-release coupling allows easy interchange of gauges when rocks of greatly differing strength are to be tested. The two quantities measured in the test are the distance, D, between platen contact points, which is read from a graduated scale incorporated in the loading frame, and the force, P, required to break the specimen, which is read from a calibrated pressure gauge in the hydraulic circuit. The *point load strength index*, I_s, is the ratio P/D^2: it may conveniently

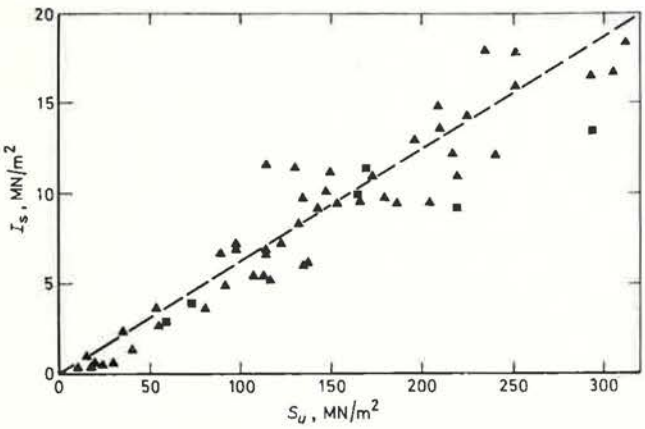

Fig. 3 Correlation between point load strength index, I_s, and uniaxial compressive strength, S_u. Results mainly after D'Andrea and co-workers[18]

be determined by use of graphs or conversion tables to avoid calculation.

This type of test is not new, having been used extensively in the U.S.A., Russia and several European countries, but mainly as a research or laboratory tool rather than as a convenient technique for field index testing. Theoretical consideration of the point load test[6,7] showed that it gives a measure of tensile strength, as, indeed, does the geological hammer. The results are, however, sufficiently related to other measures, such as unconfined compressive strength (Fig. 3) to allow this test to give an index of strength in a general sense. The point loading gives several important advantages: (1) the specimen fails at much lower loads than in compression, needing a machine load capacity less than one-tenth of that usually required for compression; (2) core can be tested direct from the core box without previous machining—even weak or broken rock can thus be tested; and (3) as fracture initiates in the specimen interior, platen contact conditions are of little importance.

Three alternative loading configurations are available for logging core. The *diametral test* (Fig. 4(*a*)), the most reproducible, is used when core sticks with a length greater than their diameter are available. The *axial test* (Fig. 4(*b*)) may be used when the core is recovered in discs or on rock discs produced by diametral testing. *Irregular lumps tests* with loading along the shortest axis may be carried out if only rock pieces are available.

As is shown in Fig. 4, results for axial testing on a highly isotropic rock correspond with those for diametral testing when the length and diameter of an axially loaded specimen are equal. When discs of this geometry cannot be obtained, the results from axial testing should be corrected for size and shape effects.

Supplementary logging

Two types of supplementary test, used to provide the supplementary logs of Fig. 1, are now discussed. Both types have applications in mining and quarrying: one is a field test; the other requires a laboratory.

The strength anisotropy index

Generally, rocks are of a non-isotropic nature, and, hence, the strength is related to the direction of the applied stresses. In foundation and excavation engineering, situations often arise in which directional aspects of strength are important, and the degree of strength anisotropy should be evaluated quantitatively. The point load test is one of the few that can easily be used for this purpose in the logging of cores (Fig. 1(*b*)).

Fig. 5 shows how the load should be applied when a core is drilled at an oblique angle to a set of weakness planes. The core is first tested diametrally along the planes of weakness, giving a minimum strength index, and then perpendicular to these planes, to obtain the maximum strength. The diametral test is arranged, where possible, to break the core into discs of equal

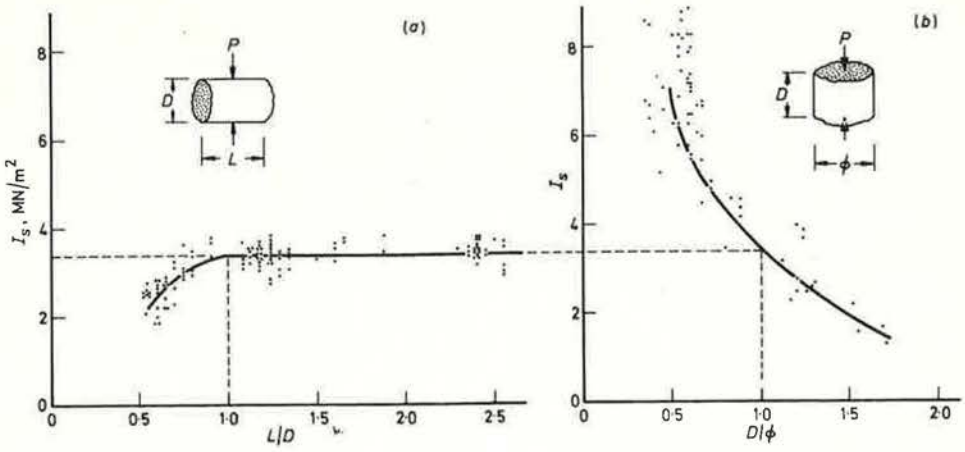

Fig. 4 Size and shape effects in the point load test: (*a*) the diametral point load test; (*b*) the axial point load test

length and diameter—the optimum shape for axial testing.

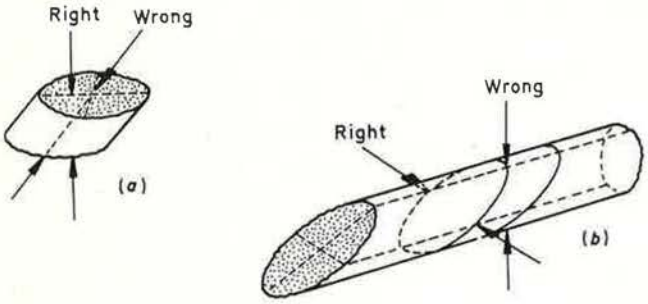

Fig. 5 Anisotropy testing—directions of loading. Maximum (*a*) and minimum (*b*) strength indices

The *strength anisotropy index*, I_a, is defined as the ratio between these maximum and minimum strength indices. The lowest value for I_a is 1, obtained when the rock is isotropic.

The slake–durability index

Short-term weathering of rocks, particularly shales and mudstones, can have a considerable effect on their engineering performance. The weatherability of these materials is extremely variable, and rocks that are likely to degrade on exposure should be further characterized by use of a test for durability.

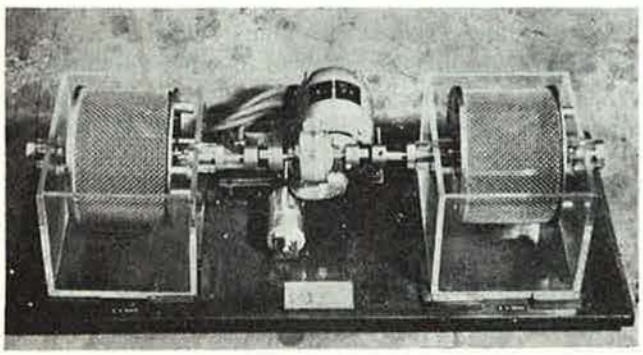

Fig. 6 Slake–durability testing equipment

The apparatus shown in Fig. 6 measures the speed of breakdown when a rock is subjected to a standard drying and wetting cycle. A sample of ten representative rock lumps, each weighing 40–60 g, is oven-dried and placed in the test drum. The drum is then half-immersed in a water-bath and slowly rotated for 10 min. The fine products of this slaking process pass through the sieve mesh that forms the body of the drum. The slake–durability index is calculated as

$$I_d = \frac{\text{Dry weight of rock retained in drum}}{\text{Dry weight of rock before slaking}}, \%$$

This index can therefore vary from 0 per cent for a rock which disintegrates completely to 100 per cent durability when no disintegration takes place. Full details of the procedure have been drafted as an international standard and they allow for variations in slake fluid (acid, salt water, etc.) to meet special requirements.[8] The test results are reproducible to within 5 per cent, and relate closely to observations by the authors of *in situ* weathering performance. A typical slake–durability log is shown in Fig. 1(*a*).

Applications

Drilling, blasting and excavation

The requirements for drilling, blasting and excavating operations are assessed mainly on an empirical basis.[9] Some mining organizations or contractors examine geological logs. In a sedimentary sequence they may note the proportions of sandstone or limestone, whereas in igneous rocks the extent of alteration or fracturing may be used as a guide to excavation problems. Others examine rock core that may have been stored and dried for several years. A few attempt seismic evaluation, but in areas of structural complexity seismic interpretation may be difficult, if not impossible. In many cases the initial choice between blasting and direct excavation is based more on speculation than on calculation.

Drilling and blasting efficiency depends largely on the tensile strength of the rocks; hence, the point load test

could reasonably be expected to predict some of the practical difficulties likely to be met in these operations. Investigations carried out in crystalline Palaeozoic and Precambrian rocks in Norway have shown that the point load strengths of core samples correlate quite well with percussive drilling rates. As would be expected, the drilling rate decreased with increasing point load strength.[10] Results from tunnel blasting in the same rock types also showed some correlation between point load strength and an index of resistance to blasting.[11] in this case of hard, massively jointed rocks the resistance to blasting decreased with increasing point load strength to an approximate point load strength of 12–15 MN/m^2, above which an increase in blasting resistance became apparent.

The ease of excavation and scale of blasting in relation to size of output also depend on preexisting fractures. On many excavation sites in sedimentary rocks the hardest rock does not always require blasting if there are abundant, open fractures or if strong and weak rocks are thinly interbedded to facilitate ripping. It is known that some of the weaker rocks (less than 1 MN/m^2 point load strength), such as mudstones, are not as easily loosened by blasting as their low strength may suggest. Weaker materials may absorb large amounts of energy when they crush in the vicinity of the drill-hole. However, the anisotropy of strength and fracture spacing can be a more important contributing factor. The log in Fig. 1 (*b*) shows most of the mudstones to be less isotropic than sandstone or muddy seatearths. Such mudstones, when blasted, often lift to fall back on bedding plane fractures along which the wave and gas pressure effects are dissipated, failing to appreciably disrupt rock in other directions. Similar anisotropy problems may occur with percussive drilling in mica-rich rocks.[10]

Recent developments towards the use of tunnelling machines involve a large financial commitment at the outset of a project. The decision to use such techniques, or the choice of a particular machine, has, at best, been based on uniaxial compressive strength and RQD.[12] The authors know of cases where this approach has proved less than adequate, and believe that the mechanical logs that have been described are more directly relevant. Rock abrasiveness, as indicated by the content of quartz and minerals of similar hardness, should also be considered when the performance of both tunnelling machines and drilling equipment is being predicted, and it could be presented as a supplementary log.

Stability of rock structures

Rock structures, such as slopes, foundations and underground openings, can be designed by use of a variety of mathematical methods. The calculations, however, involve simplifying assumptions that must be kept in perspective by continual comparison with the real and complex rock environment. For this purpose plans and sections, known as 'rock quality maps', which show variation in the mechanical properties of a rock mass are invaluable. For example, detailed calculations on the strength of a rock joint would be of little value if the joint were neither continuous nor critically located. Rock quality maps can also be used in the siting of large-scale design tests, and can help in the planning of grouting, rock bolting and drainage systems. Empirical design techniques, in particular,[13] require an accurate assessment of rock quality.

The stability of a rock structure depends on the mass properties of strength and deformability, and large-scale tests would be required to determine these directly. Such tests are, however, slow and expensive, and indirect index tests are required which relate to these two aspects of rock mass performance. No direct proof can be given that fracture spacing and intact strength are the two most relevant index properties—the complex properties of a rock mass involve shearing, sliding and interlocking of constituent blocks, and require further investigation. There are, however, indications that fracture spacing and strength are important: for example, closely fractured rock (low I_f) is likely to behave in a granular fashion, and may be traversed by a failure surface even though the intact material is strong. These two properties have frequently been used as a basis for predicting rock stability, and appear to have worked well in practice. Terzaghi,[14] in assessing tunnel support systems, used terms such as 'intact rock', 'blocky and seamy rock', and 'crushed rock', and recent detailed foundation investigations on chalk[15] employed a similar approach, both methods being based on estimates of fracture spacing and strength. A similar, but quantitative, rock quality classification based on these two indices is described later.

Supplementary observations on joint orientation, tightness, roughness and infilling are required, since these properties also have an important influence on strength and deformability of a rock mass. In logging the core, even thin units should be carefully observed since they may be extensive and could have an overriding influence on stability.[16] These features frequently require supplementary testing.

Selection and performance of rock aggregates

The point load test may prove a simple and reliable alternative to standard strength and crushing tests used for quality control of road and concrete aggregates. If so, the same rock quality maps could be used for aggregate selection as are used in other applications. When one is prospecting for rock fill, the potential size grading as well as the strength of materials must be considered—marine works, for example, call for heavy blocks that will remain in place despite strong wave action. Rock-fill embankments are commonly constructed from material that is carefully size-graded to give the right permeability characteristics. Fracture spacing maps can indicate the sizes likely to result from blasting, and can therefore assist in planning an economic extraction and haulage programme.

Although the usual problem is to find rock of sufficient strength for use as aggregate, there are cases where rock is too hard. Tyre wear at some open-pit sites and tunnels can be extremely high, especially if rock does not readily break down and if suitably graded crushed rock is not available. Point load testing should help to identify those rocks likely to give trouble. Rolled mudrocks are frequently used to surface access

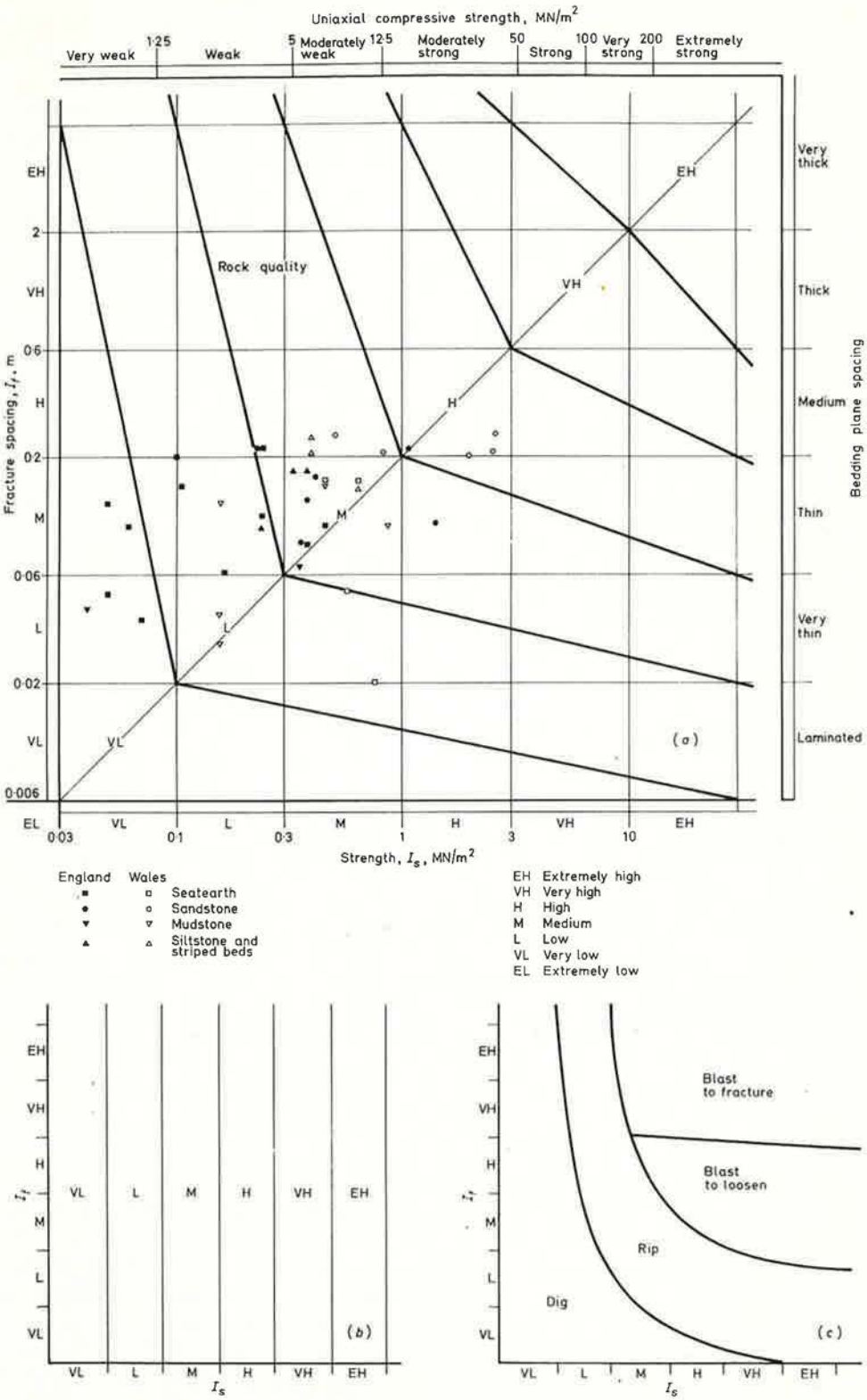

Fig. 7 Rock quality classification diagrams: (*a*), general purpose classification (plotted points refer to logs in Fig. 1) (the subdivision on the top and that on the right of the diagram refer to suggestions by the Geological Society of London[4]); (*b*) and (*c*), alternative methods of subdivision (see text)

roads since grading is produced in the rolling operation. Supplementary durability testing will show whether breakdown in wet conditions is likely to be acceptable, or so excessive as to cause bogging of plant and machinery.

Rock quality

A classification diagram can be used to combine two separate indices, such as strength and fracture spacing, to give a single 'rock quality index'. The method of subdividing such a diagram depends on the relative weight to be placed on each contributing index—the required weighting will vary depending on the application. Fig. 7(*a*), for example, has been subdivided by use of straight lines. A change in the inclination of these lines has been used to move the weighting from one index to the other. Fig. 7(*b*) shows a subdivision that might apply to the quality of rock as a road aggregate: the subdividing lines are vertical, showing that the quality is affected by strength, but that fracture spacing has no significance. If, as in this case, one index is unimportant, then its place on the diagram may be taken by another, such as a durability or an anisotropy index.

Fig. 7(*c*) shows the situation more likely to obtain in practice, where the subdivision, instead of being arbitrary, would be based on experience—the diagram relates to rock excavation. Each subdividing line now shows the capability limits for a particular type of excavating machine. The quality of a particular suite of rocks is determined by plotting each rock unit, in this case the units of core that were logged in Fig. 1, as a single point located on the diagram by means of its two mechanical index values.

Subdivision of the classification diagram into rock quality zones must therefore be based on practical experience, and the methods might well vary depending on the application. Until the indices have been more widely applied, the authors are employing the general-purpose subdivision of Fig. 7(*a*). The index axes themselves have been subdivided. Some engineers or geologists prefer to use terms such as 'extremely strong' or 'closely fractured' rather than the more precise numerical values. The subdivisions of Fig. 7(*a*) are based on those proposed by the Geological Society,[4] which, in turn, are the result of an extensive review of many available alternatives. The strength subdivision has, however, been transposed from uniaxial strength to point load strength, the correlation given in Fig. 3 being used, with some slight adjustments to the boundaries for convenience. Future studies will also need to consider how best to incorporate supplementary test information in an assessment of rock quality. Frequently, a supplementary index plays too important a role to be neglected, but it is difficult to apply the graphical methods used in Fig. 7 when a classification involves three or more variables. Computer techniques are available to assist with these more complex classification problems.[17]

Acknowledgement

The development of testing techniques was financed by the sponsors of the Rock Mechanics Project, Royal School of Mines, London, under the direction of Professor E. Hoek.

The Opencast Executive of the National Coal Board kindly allowed publication of our test results on prospecting cores.

The authors are grateful for generous assistance from many colleagues and associates who helped during development, especially L. Wilson, J. Sullivan and R. Chandra, Royal School of Mines; I. Cottis and R. Dowell, formerly Drilling and Prospecting International, Ltd.; and those from Engineering Laboratory Equipment, Ltd.

The opinions expressed are those of the authors and not necessarily those of the sponsors.

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ATTACHMENT D

Client:	Apex Companies, LLC
Project Name:	South Terminal Extension
Project Location:	New Bedford, MA
GTX #:	10697
Test Date:	07/30/11
Tested By:	daa
Checked By:	mpd

Bulk Density and Compressive Strength of Rock Core Specimens by ASTM D 7012 Method C

Boring ID	Sample ID	Depth, ft	Bulk Density, lb/ft^3	Compressive Strength, psi	Failure Type	In conformance with ASTM D 4543
B3	Rock Core	2.19-2.56	161	15,510	1	YES
B4	Rock Core	58.99-59.36	164	12,926	1 & 2	NO *
B9	Rock Core	1.52-1.89	164	14,656	1	YES
B9A	Rock Core	3.16-3.53	180	15,159	1	YES
B10	Rock Core	1.09-1.46	173	19,138	1	YES
B11	Rock Core	2.45-2.82	163	7,575	2	YES
B19	Rock Core	4.12-4.49	165	15,429	1	YES
B31	Rock Core	5.39-5.76	162	36,367	1	YES
B32	Rock Core	1.43-1.80	163	11,542	2	YES

A-2010-B3/C1
A-2010-B4/C2
2.86-3.23
A-2010-B9/C1
A-2010-B9A/C1
A-2011-B10/C1
A-2011-B11/C1
A-2011-B19/C1
A-2011-B31/C2
A-2011-B32/C1

Notes: Density determined on core samples by measuring dimensions and weight and then calculating.
All specimens tested at the approximate as-received moisture content and at standard laboratory temperature.
Failure Type: 1 = Intact Material Failure; 2 = Discontinuity Failure (See attached photographs)
* The as-received core did not meet the ASTM side straightness tolerance. Best effort end preparation.
See Tolerance report for details.

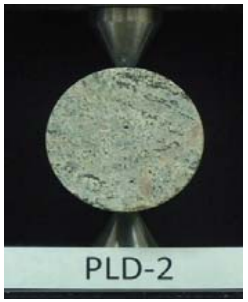
Client:	Apex Companies, LLC	Test Date:	10/21/11
Project Name:	South Terminal Extension	Tested By:	daa/jsc
Project Location	New Bedford, MA	Checked By:	mpd
GTX #:	10697	Sample Type:	rock core

Point Load Strength Index of Rock by ASTM D 5731

A-2010-B2/C1

Boring No.	Sample No.	Depth, ft.	Test No.	Test Type	Specimen Diameter (D), in.	Specimen Length (L), in.	Failure Load (P), lbs.	D_e^2, in^2	D_e, in.	I_s, psi	F	$I_{s(50)}$, psi	Generalized Correction Factor, K	Estimated Compressive Strength, psi
B2	Rock Core	---	PLD - 2	Diametral	1.99	3.14	1594	3.97	1.99	401	1.006	403	23	9,230

PLD - 2
before



PLD - 2
after

Intact Material Failure

Notes: Generalized correction factor, K, used to estimate the compressive strength based on the specimen depth and ASTM D 5731 Table 1.
D_e = the equivalent core diameter
I_s = the uncorrected point load strength index
F = the size correction factor
$I_{s(50)}$ = the size corrected point load strength index

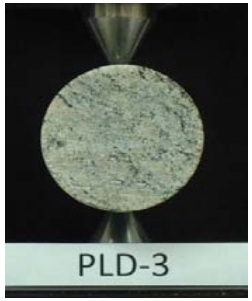
Client:	Apex Companies, LLC	Test Date:	10/21/11
Project Name:	South Terminal Extension	Tested By:	daa/jsc
Project Location	New Bedford, MA	Checked By:	mpd
GTX #:	10697	Sample Type:	rock core

Point Load Strength Index of Rock by ASTM D 5731

A-2011-B18/C1

	ample No.	Depth, ft.	Test No.	Test Type	Specimen Diameter (D), in.	Specimen Length (L), in.	Failure Load (P), lbs.	D_e^2, in^2	D_e, in.	I_s, psi	F	$I_{s(50)}$, psi	Generalized Correction Factor, K	Estimated Compressive Strength, psi
B18	Rock Core	---	PLD - 3	Diametral	1.99	3.27	4026	3.94	1.99	1021	1.004	1025	23	23,500

PLD - 3
before



PLD - 3
after

Intact Material Failure

Notes: Generalized correction factor, K, used to estimate the compressive strength based on the specimen depth and ASTM D 5731 Table 1.
D_e = the equivalent core diameter
I_s = the uncorrected point load strength index
F = the size correction factor
$I_{s(50)}$ = the size corrected point load strength index

ATTACHMENT E

South Terminal Boring Program
Photo Log of Rock Cores

Over Water Boring Program:

Photo 1: Rock Core A-2010-B1: C1 top, C2 2nd from top and A-2010-B2: C1 3rd from top, C2 4th from top.
Left side of box represents the shallowest elevation of core.

Photo 2: Rock core A-2010-B3: C1 top, C2 2nd from top, and A-2010-B4: C1, C2, and C3 3rd from top, C4, & C5 4th from top.
Left side of box represents the shallowest elevation of core.

South Terminal Boring Program
Photo Log of Rock Cores

Photo 3: Rock core A-2011-B5: C1 top, C2 2nd from top, C3 3rd from top.
Left side of box represents the shallowest elevation of core.

Photo 4: Rock core A-2010-B6: C1 2nd from top, C2 3rd from top & A-2010-B7: C1 4th from top.
Left side of box represents the shallowest elevation of core.

South Terminal Boring Program
Photo Log of Rock Cores

Photo 5: Rock core A-2010-B7: C2 top, & A-2010-B8: C1 2nd from top, C2 3rd from top & A-2010-B9: C1 4th from top.
Left side of box represents the shallowest elevation of core.

Photo 6: Rock core A-2010-B9: C2 top, & A-2010-B9A: C1 2nd from top, C2 3rd from top, C3 4th from top.
Left side of box represents the shallowest elevation of core.

South Terminal Boring Program
Photo Log of Rock Cores

Photo 7: Rock core A-2011-B10: C1 top, C2 2nd from top, C3 3rd from top, C4 4th from the top.
Left side of box represents the shallowest elevation of core.

Photo 8: Rock core A-2011-B11: C1 top, C2 2nd from top, & A-2011-B12: C1A and C1B 3rd from top, C2 4th from top.
Left side of box represents the shallowest elevation of core.

South Terminal Boring Program
Photo Log of Rock Cores

Photo 9: Rock core A-2011-B12: C3A top, C3B top and 2nd from top, C4 2nd and 3rd from top.
Left side of box represents the shallowest elevation of core.

Photo 10: Rock core A-2011-B13: C1 top, C2 2nd from top C3 3rd from top.
Left side of box represents the shallowest elevation of core.

South Terminal Boring Program
Photo Log of Rock Cores

Photo 11: Rock core A-2011-B14: C1 top, C22nd from top, & A-2011-B15: C1 3rd from top, C2 4th from top. Left side of box represents the shallowest elevation of core.

Photo 12: Rock core A-2011-B15: C3 top, C4 2nd from top & A-2011-B16: C1 3rd from top, C2 4th from top. Left side of box represents the shallowest elevation of core.

South Terminal Boring Program
Photo Log of Rock Cores

Photo 13: Rock core A-2011-B16: C3 top, C4 2nd from top, C5 3rd from top.
Left side of box represents the shallowest elevation of core.

Photo 14: Rock core A-2011-B18: C1 top, C2 2nd from top, C3 3rd from top.
Left side of box represents the shallowest elevation of core.

South Terminal Boring Program
Photo Log of Rock Cores

Photo 15: Rock core A-2011-B19: C1 top, C2 2nd from top, & A-2011-B20: C1 3rd from top, C2 4th from top.
Left side of box represents the shallowest elevation of core.

Photo 16: Rock core A-2011-B21: C1 top, C2 2nd from top, C3 3rd from top.
Left side of box represents the shallowest elevation of core.

South Terminal Boring Program
Photo Log of Rock Cores

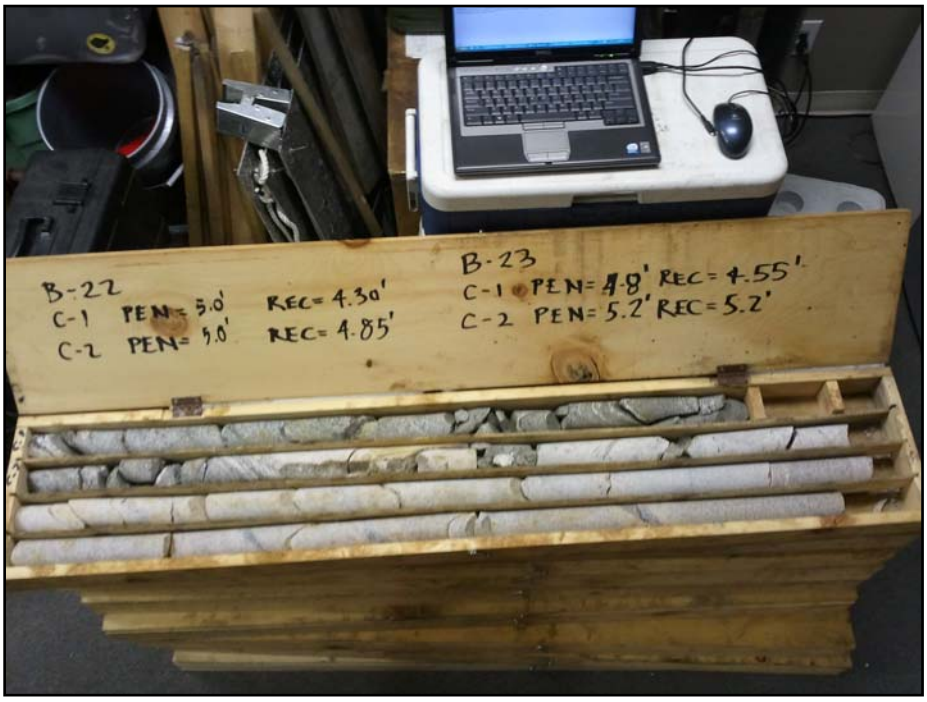


Photo 17: A-2011-B22: C1 top, C2 2nd from top, & A-2011-B23: C1 3rd from top, C2 4th from top.
Left side of box represents the shallowest elevation of core.

Photo 18: Rock core A-2011-B24: C1 top, C2 2nd from top, & A-2011-B25: C1 2nd from top, C2 3rd from top, C3 4th from top.
Left side of box represents the shallowest elevation of core.

South Terminal Boring Program
Photo Log of Rock Cores

Photo 19: Rock core A-2011-B26: C1 top, C2 2nd from top, & A-2011-B28: C1 3rd from top, & A-2011-B29: C1 4th from top.
Left side of box represents the shallowest elevation of core.

Photo 20: Rock core A-2011-B31: C1 top, C2 2nd from top, C3 3rd from top, C4 4th from top.
Left side of box represents the shallowest elevation of core.

South Terminal Boring Program
Photo Log of Rock Cores

Photo 21: Rock core A-2011-B32: C1 top, C2 2nd from top, C3 3rd from top, C4 4th from top.
Left side of box represents the shallowest elevation of core.

Land Boring Program:

Photo 22: Rock core A-2011-LB-B1: C1 top, C2 2nd from top, & A-2011-LB-B2: C1 3rd from top.
Left side of box represents the shallowest elevation of core.

South Terminal Boring Program
Photo Log of Rock Cores

Photo 23: Rock Core A-2011-LB-B4: C1 top A-2011-LB-B5 C1 2nd from top A-2011-LB-B8: C1 3rd from top, A-2011-LB-B6: C1 4th from top.
Left side of box represents the shallowest elevation of core.

Photo 24: Rock Core A-2011-LB-B9-MW-6: C1 top, and A-2011-LB-B10: C1 2nd from top, C2 3rd from top, C3 4th from top.
Left side of box represents the shallowest elevation of core.

South Terminal Boring Program
Photo Log of Rock Cores

Photo 25: Rock Core A-2011-LB-B10: C4 top, C5 2nd from top, C6 3rd from top.
Left side of box represents the shallowest elevation of core.

Photo 26: Rock Core A-2011-LB-B13: C1 2nd from top, C2 3rd from top and A-2011-LB-B14: C1 4th from top.
Left side of box represents the shallowest elevation of core.

South Terminal Boring Program
Photo Log of Rock Cores

Photo 27: Rock Core A-2011-LB-B14: C2 top, and A-2011-LB-B15: C1 3rd from top, and A-2011-LB-B16: C1 4th from top.
Left side of box represents the shallowest elevation of core.

Photo 28: Rock Core A-2011-LB-B17: C1 top and A-2011-LB-B18: C1 2nd from top.
Left side of box represents the shallowest elevation of core.

South Terminal Boring Program
Photo Log of Rock Cores

Photo 29: Rock core A-2011-LB-B19: C1 top and A-2011-LB-B20: C1 2nd from top & A-2011-LB-B21: C1 3rd from top, C2 4th from top.
Left side of box represents the shallowest elevation of core.

CAD 3 Boring Program:

Photo 30: Rock core A-CAD3-2011-B3: C1 & C2 3rd from top & A-CAD3-2011-B5 4th from top, & A-CAD3-2011-B6 2nd from top.
Left side of box represents the shallowest elevation of core.

South Terminal Boring Program
Photo Log of Rock Cores

Photo 31: Rock core A-CAD3-2011-B7: C1 top, & A-CAD3-2011-B8: C1 2nd from top.
Left side of box represents the shallowest elevation of core.

ATTACHMENT F

DRAFT

AFTER ACTION REPORT

ON THE FISH KILLS RESULTING FROM BLASTING IN SUPPORT OF ROCK REMOVAL FROM THE FEDERAL NAVIGATION PROJECT -BOSTON HARBOR, MASSACHUSETTS- (FALL 2007)

PREPARED BY:

U.S. Army Corps of Engineers
New England District

JUNE 2008

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SUBJECT

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Table 2. Information on Each Blast Event
Table 3. Date, Location, and Approximate Number of Fish Killed

FIGURES
Figure 1. Project Map
Figure 2. Rock Removal Locations and Dates

AFTER ACTION REPORT

I. Introduction

A. Purpose of the Report

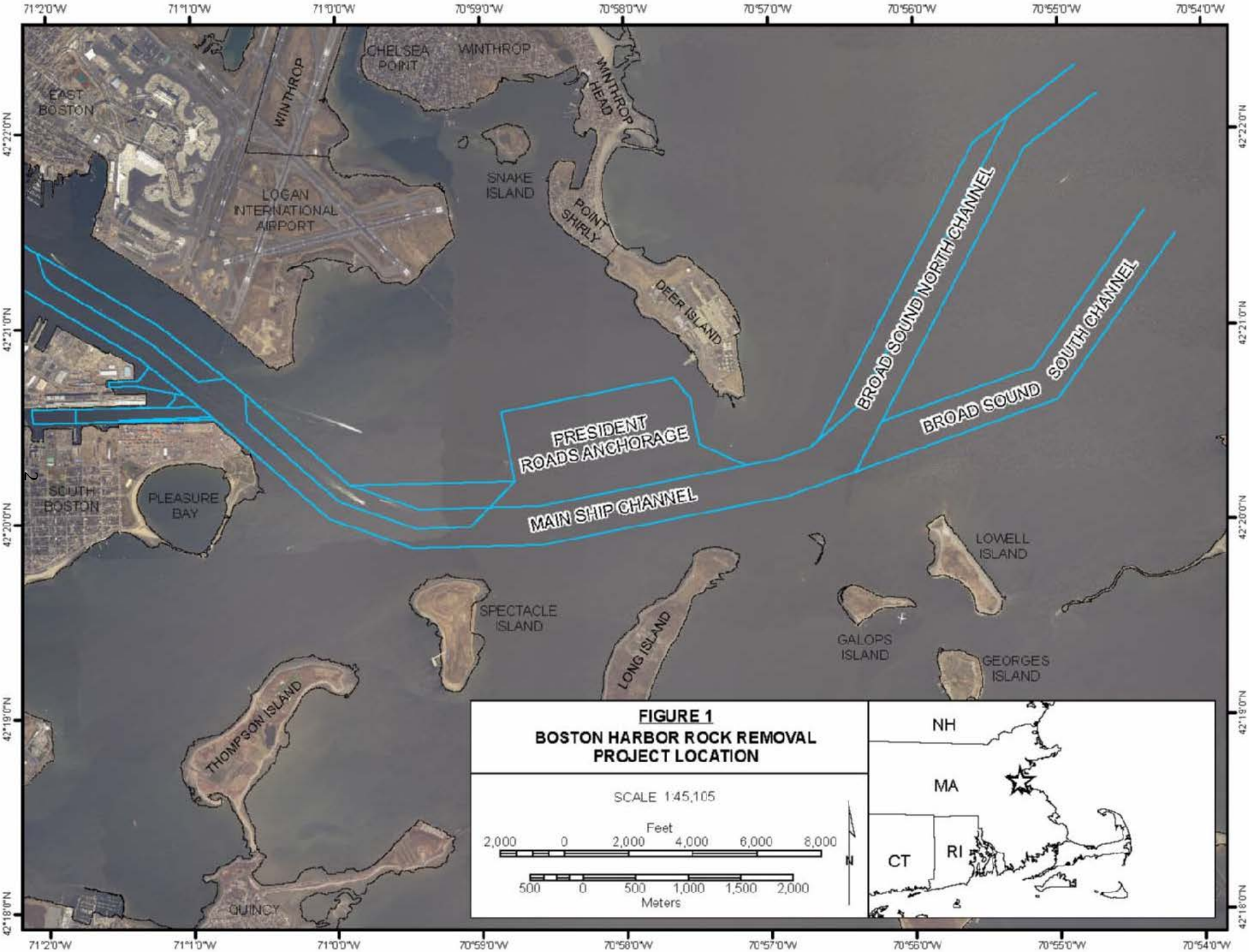
The purpose of this After Action Report (AAR) is to (1) document the project activities that resulted in fish kills, (2) the follow-up actions taken, and (3) the lessons learned during rock removal operations from the Federal channel and anchorage area in Boston Harbor, Boston, Massachusetts during 2007. The lessons learned from these blast events will be used to prepare a comprehensive blast plan for the upcoming Boston Harbor Deep Draft Navigation Improvement Project. In addition to the lessons learned from the events described in this AAR, a comprehensive blast plan to be developed for the Boston Harbor Deep Draft Project will also incorporate pertinent information obtained through literature reviews, advice from technical experts, lessons learned from other dredging/rock removal projects, results of resource agency coordination, and input from the project technical working group (TWG) sub-committee established specifically for this effort.

B. Project Description

It was discovered during maintenance dredging of the Boston Harbor Federal navigation channels in 2004 and 2005 that several areas of rock extended above the authorized navigation channel depths. These rock areas were located in the Main Ship Channel, President Roads Anchorage, and in the Broad Sound North Channel (see Figure 1). To eliminate this hazard to navigation and achieve authorized depths, it was necessary to remove this rock through blasting. A contract to remove the rock was awarded on March 15, 2007 to RDA Construction Corp. of Quincy, Massachusetts. RDA Construction began work in Boston Harbor in September 2007. They began to drill and blast in the President Roads Anchorage the week of October 1, 2007 and continued work until December 23, 2007 when operations were suspended in the Broad Sound North Channel due to safety concerns resulting from rough winter weather conditions. RDA Construction resumed work in April 2008. A hydraulic ram was used in the Broad Sound North Channel to remove the remaining rock material in the spring and summer of 2008. Table 1 provides the location, volumes of material removed, dates, and rock removal methods from the three locations containing the rock in the harbor.

Table 1. Information on Rock Removed From Each Section in Boston Harbor

Location	Amount (cy)	Dates	Method of Removal
President Roads Anchorage	1,029	Oct-Nov 2007	Blast
Main Ship Channel	235	November 2007	Blast
Broad Sound North Channel	42 XX	December 2007 April–June 2008	Blast Hydraulic Ram


71°2'0"W
71°1'0"W
71°0'0"W
70°59'0"W
70°58'0"W
70°57'0"W
70°56'0"W
70°55'0"W
70°54'0"W
42°22'0"N
42°21'0"N
42°20'0"N
42°19'0"N
42°18'0"N
EAST BOSTON
WINTHROP
CHELSEA POINT
WINTHROP
WINTHROP HEAD
SNAKE ISLAND
LOGAN INTERNATIONAL AIRPORT
POINT SHIRLY
DEER ISLAND
BROAD SOUND NORTH CHANNEL
BROAD SOUND SOUTH CHANNEL
BROAD SOUND
PRESIDENT ROADS ANCHORAGE
MAIN SHIP CHANNEL
SOUTH BOSTON
PLEASURE BAY
LOWELL ISLAND
SPECTACLE ISLAND
LONG ISLAND
GALOPS ISLAND
GEORGES ISLAND
THOMPSON ISLAND
QUINCY
FIGURE 1
BOSTON HARBOR ROCK REMOVAL PROJECT LOCATION
SCALE 1:45,105
Feet
2,000 0 2,000 4,000 6,000 8,000
500 0 500 1,000 1,500 2,000
Meters
N
NH
MA
CT
RI

C. Operational and Construction Measures to Reduce Fish Impacts From Underwater Blasting

Blasting generates underwater shock waves which radiate from the point of the blast. These shock waves can injure or kill fish that transit or inhabit the impact area. Injuries can result either directly from the blast or when air bladders of the fish are impaired. To reduce the potential for fishery impacts, blast procedures were established for this project and approved by regulatory agencies prior to construction. These procedures seek to reduce shock waves in the overlying water column and deter schools of fish from the area at the time of blasting. Construction procedures implemented to reduce the shock wave included using inserted delays of a fraction of a second and stemming. Stemming is a method used to deaden the shock wave reaching the over-laying water column by placing stone or similar material into the top of the borehole. Operational procedures implemented to reduce potential impacts to fisheries in the areas of blasting included the use of side scan sonar to detect and avoid passing schools of fish during blasting, a fish startle system to deter fish of the Clupeid family (i.e. blueback herring and alewife) from entering the blast area, and a fish observer to oversee and coordinate these efforts and determine the appropriate blast time to avoid fishery impacts. The credentials of the fish observer, Eric Rydbeck of Normandeau Associates, were approved by the National Marine Fisheries Service (NMFS) on September 25, 2007 and MA Division of Marine Fisheries (MA DMF) on September 28, 2007.

The fish observer used hydroacoustic monitoring (i.e. side-scan sonar) prior to any blasting event to determine that schools of fish were not located within or transiting the blast zone area. In addition to the side-scan sonar, a fish startle system (Sonalysts, Inc.) was employed which is capable of deterring fish from the Clupeid family using high amplitude sound at specific frequencies.

The established procedure implemented by the fish observer during blast events was to first deploy the side scan equipment off a support vessel that navigated around the blast site to check for the presence of fish in the area. However, the presence of blast cords in the water column limited the ability of the vessel to completely circle around the area. As a result, only approximately 320° to 340° around the blast site could be monitored using this technique. The side scan sonar covers 150 feet on either side of the vessel. The fish observer made as many passes around the blast site as needed to feel confident there were no fish in the area. A minimum of two passes with no observed fish were conducted prior to approving the initiation of the blasting procedure.

The fish startle system was deployed prior to each blast event, regardless of whether fish were observed in the area, and removed from the water approximately five minutes before the blast for all events regardless if fish were observed in the area. The fish startle system was located on the blast barge and was deployed in the area of blasting to a depth of 10 feet off the seafloor, consistent with operating procedures described in the manufacture's manual. The fish startle system was removed from the water prior to the blast. The manufacturer of the fish startle system indicated that the fish startle system

can be removed from the water column up to 10 minutes before the blast and still be effective.

D. Blasting Specifications, Procedures and Safety Plan

Explosive products manufactured by Orica, USA were 2 or 2 ½" by 16", 40% gelatin charges. Non-electric delay blasting caps manufactured by Orica, USA were used. The bore holes were a minimum three inches in diameter, spaced a minimum of five feet apart, with a minimum five foot overburden. The average drill depth of the hole was eight feet with a minimum of three feet of stemming utilizing 1/8" peastone.

Drilling was conducted from the barge with a Joy Mini-mustang equipped with a drilling nose to center the drill bit on the channel floor. The drilling nose was advanced to the floor via cable and winch on a drill. The drill steel was advanced to the nose. The diver guided the bit and still into the nose. The diver then surfaced and then the borehole was dug to the proper depth. The diver returned to the floor with a section of a PVC pipe, the nose was lifted and the PVC pipe inserted into the drill hole to keep the hole open and free from bottom silt. This was repeated until the area was completely drilled.

Packages of explosives and cap were assembled on the deck of the barge using 80 foot Nonel caps. Those packages were then lowered to the diver via a tag line weighted to the bottom. The diver inserted the package into the open hole through the PVC sleeve. The peastone was then lowered via a tag line and the hole stemmed. The Blaster marked and secured the surface delay on the deck of the barge. The process was repeated until the shot was fully loaded and stemmed. The circuit was "snapped" together on the deck of the barge in proper sequence to a "shock tube" lead-in-line. Surface delays were attached to plastic jugs with the lead line shock tube beading back to the barge for initiation by the Blaster. After clearing the vessel traffic and barge personnel, the whistle system described below was sounded and the blast fired. There was no drilling during loading operations. Each operation is completed prior to the next operation. The line was run out to a safe distance from the blast site to the Blaster.

Prior to initiating the blast, a whistle signal system was sounded at which time all equipment and personnel were moved from the danger zone. The whistle system began with warning signal of a one-minute series of long whistles five minutes prior to the blast. The second blast signals were identified by a series of short whistles which were sounded one minute to the blast. After the second set of signals and before initiation, the Blaster visually checked with each guard to obtain the final all-clear. The all-clear signal was sounded with one prolonged whistle once the blast was made and the inspection finalized.

After the blast, the Blaster inspected for misfires and then sounded the all-clear. If a misfire was noted, the following OSHA recommendations were followed:

- If a misfire was found, the Blaster provided proper safeguards for excluding all employees from the danger zone.

- No other work began except those necessary to remove the hazard of the misfire and the employees necessary to do the work remained in the danger zone.
- No attempt was made to extract explosives from any charged or misfired hole; a new primer would be installed and the hole reblasted.
- If there were any misfires while using cap and fuse, all employees would remain away from the charge for at least one hour. Misfires were to be handled under the direction of the Blaster. All wires would be carefully traced and a search made for unexploded charges.
- No drilling, digging, or picking was permitted until all missed holes were detonated or the authorized representative has approved that work could proceed.

No blasting occurred between sunset and sunrise. All blasting was required to be completed 45minutes before sunset. Once blasting was completed for the day, the explosives were returned to the truck and transported back to permanent storage at Orica USA in Templeton, MA. No explosives were stored on site overnight.

II. Information on Blasting in Boston Harbor Fall 2007

Blasting was initiated on October 5, 2007 to remove rock from Boston Harbor. No fish kills were experienced through the first seven blasts in the President Roads Anchorage area. A total of 14 blast events occurred in the fall of 2007 in Boston Harbor, of which four resulted in a fish kill of varying magnitude. The first fish kill event occurred during the eighth blast event on October 24, 2007. Table 2 below provides the location, dates, tidal conditions, and other pertinent information for all blast events. Figure 2 shows the blasting locations and the dates for each location.

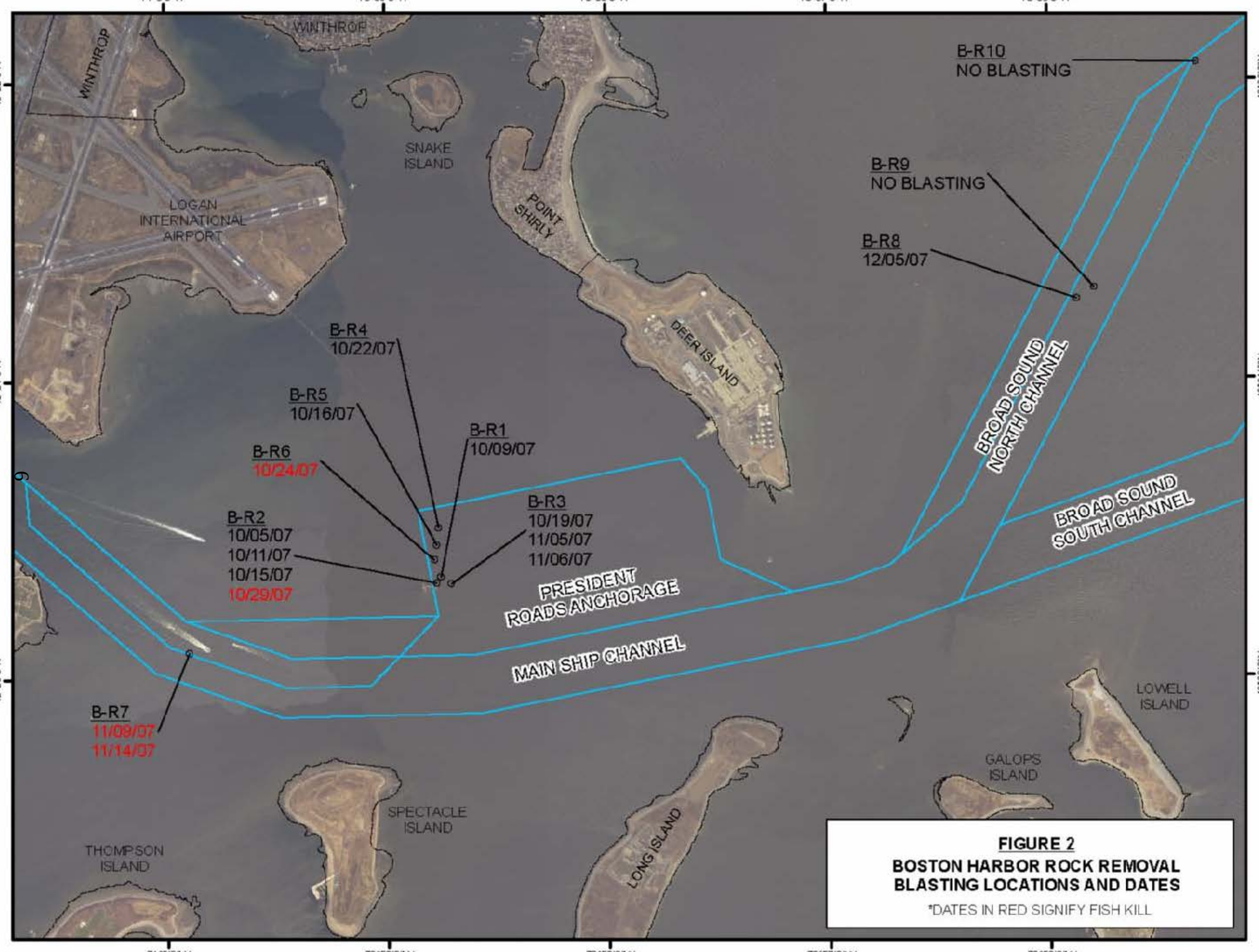


FIGURE 2

BOSTON HARBOR ROCK REMOVAL BLASTING LOCATIONS AND DATES

*DATES IN RED SIGNIFY FISH KILL

Table 2. Information on Each Blast Event

Date (2007)	Location*	Weather Low/High/Rain (^{0}F/inches)	Tide	Time of Blast (PM)	Current Speed (mph)	No. of Bore Holes	Explosive (pounds)	Fish Kill
October 5	PR Anchorage	67/75	2h03m after high tide	3:18	5	34	819	No
October 9	PR Anchorage	52/61	30m before high tide	4:25	15	25	624	No
October 11	PR Anchorage	52/63/.50”	1h21m after high tide	1.23	10	36	897	No
October 15	PR Anchorage	52/66	33m after high tide	2:59	10	34	836	No
October 16	PR Anchorage	52/70	1h08m before high tide	2:00	12	29	702	No
October 19	PR Anchorage	65/70/.50”	2h58m before high tide	2:45	7	30	819	No
October 22	PR Anchorage	65/72	34m before low tide	1:52	10	28	819	No
October 24	PR Anchorage	56/64	3h20m before low tide	12:54	7	14	351	Yes
October 29	PR Anchorage	37/65	12m after high tide	2:17	10	31	858	Yes
November 5	PR Anchorage	40/55/.62”	2h08m after low tide	4:05	10	32	858	No
November 6	PR Anchorage	37/51	59m after low tide	3:46	15	34	854.1	No
November 9	Main Ship Channel	32/43	45m before low tide	4:05	5	29	819	Yes
November 14	Main Ship Channel	37/60	3h39m after low tide	1:49	15/20	8	214.5	Yes
December 5	North Channel	24/32	55m after low tide	3:11	10	22	565.5	No

*PR Anchorage=President Roads Anchorage

III. Fish Kill Events During Blasting

Despite the construction and operational fish avoidance procedures implemented, as described above in Section C, four fish mortality events were experienced over a three-week period during blast operations in the President Roads Anchorage and Main Ship Channel areas. Table 3 below provides the dates, locations, and information on approximate number of fish observed killed from each blast event. Appendix A provides the number of dead fish species collected for each fish kill event. The length and weight for individuals collected and recorded for three of the four blast events are presented in Appendix B. Length and weights for fish collected during the first blast event, October 24, 2007, were not available. The details for each fish kill event are described below.

Table 3. Date, Location, and Approximate Number of Fish Killed

Date	Location	Approximate Number of Observed Fish Killed
October 24, 2007	President Roads Anchorage	150
October 29, 2007	President Roads Anchorage	1,000
November 9, 2007	Main Ship Channel	900-1,000
November 14, 2007	Main Ship Channel	300

A. Fish Kill Number 1

1. Event Specifics

The first fish kill event occurred on October 24, 2007. The fish observer made two passes on a support vessel with the side scan sonar around the blast zone. The initial sweep identified what was believed to be a school of fish near the surface within the blast area. A second sweep was conducted and no schools of fish were observed. The startle system was removed and the blast sequence initiated. See Section C above. The blast was detonated at 12:54 pm.

After blasting occurred approximately 150 dead or injured fish were observed floating at the surface. The fish observer collected the floating fish, which he counted and identified to species. For this event, 124 rainbow smelt (*Osmerus mordax*), two alewife (*Alosa pseudoharengus*), 23 cunner (*Tautogolabrus adspersus*), three red hake (*Urophycis chuss*), and one butterfish (*Peprilus triacanthus*) were collected.

2. Discussion of a Possible Cause and Corrective Action(s) Taken

The Corps contract specification for rock removal activities required that "If at any time during the implementation of the project, a significant fish kill or significant water quality problem occurs, and can be attributed to the project, all site activities impacting the water shall cease until the source of the problem is identified. Adequate mitigating measures shall be followed as outlined in the contingency plan or upon discussion with the appropriate state and local agencies." Upon observation of the fish kill, the Corps resident engineer directed that all blasting activity cease until a mitigation/contingency

plan could be developed through coordination with affected resource agencies (NMFS, MA DMF, and the MA Department of Environmental Protection (MA DEP)). Based on the information received, NMFS stated that they considered this a significant fish kill.

As a follow-up corrective action, the Corps performed a system review to ensure that all equipment was working properly, calibration and monitoring protocols were implemented correctly, and identify corrective measures, if any, to minimize the potential for reoccurrence of a similar event. To verify that the equipment was working properly, a technician from Sonalysts (fish startle system) checked the equipment and confirmed that the system was in fact fully operational and functioning properly.

The fish startle system was located on the blast barge, deployed to a depth of 10 feet off the bottom, and removed from the water approximately one minute prior to the blast, as also outlined in the manufacturer's procedures.

After confirmation that all equipment was properly functioning and that all operational procedures had been followed, it was determined that the fish kill was most likely due to the movement of fish into the blast area after it had been scanned and cleared by the sonar system. Although two passes were made around the blast area and no fish were observed in the second pass, it is probable that fish had moved into the area through a previously scanned and cleared zone while the vessel was completing its sweeping activity of another section of the blast perimeter.

The side scan sonar projects from the vessel down to the bottom at an angle. This could result in a small "inverted cone" of the water column not being scanned as the vessel transits the perimeter of the blast site. To increase the field of vision within the water column, a modified scanning procedure was to be implemented for all future blast events. The fish observer on the sonar vessel was instructed to begin screening for schools of fish as close as possible to the blast center. He then was to move out in a spiral to capture nearly the entire water column from the surface to the bottom throughout the blast area. It was thought that this technique would minimize the potential for fish schools to enter the blast zone undetected.

B. Fish Kill Number 2

1. Event Specifics

The second fish kill occurred during the ninth blast event on October 29, 2007. At approximately 12:30 pm the loading of the charges was completed. At 12:50 pm the fish startle system was deployed from the blast support barge located within the blasting zone. At 1:00 pm the side scan sonar was deployed and activated off a support vessel that moved along the perimeter of the blast zone monitoring for schools of fish. The side scan sonar vessel traversed the majority of the blast zone circumference but avoided that portion of the area where the down tubes are located which could result in severed lines and unexploded charges. The fish observer identified schools of fish transiting the area and subsequently performed additional sweeps (approximately 20) which showed varying

amounts of fish within and transiting the area. The fish observer observed and noted that there were unusually high numbers of fish in the area. The side scan sonar had indicated that fish were rapidly moving in and out of the blast area.

As the day progressed, less fish were observed transiting through the area. The fish observer, Contractor and the Corps construction representatives evaluated the situation to try and determine what if any operational conditions might potentially be attracting fish to the blast area and what steps could be taken to discourage fish from entering the project area. Based on the sonar observations it was speculated that the fish were potentially being attracted to the shadow projecting from the barge within the water column. It was also possible that suspended organic debris in the blast area resulting from a nearby dredging operation removing rock from earlier blasts could also be attracting fish to the area. It was generally concluded that moving the barge back from the blast zone as an implementable measure that may serve to reduce fish in the area.

At 2:02 pm the barge started to pull back from the blast zone. Once this was accomplished, the Contractor assumed that it was necessary to commit to initiating the blast sequence within 10 minutes since the fish startle system was relocated beyond the range of effectiveness for the entire blast zone. Vendor specifications state that the startle system should be deployed until 10 minutes before the blast since fish would not return to the area until 15 minutes after deactivation.

In the event blasting does not occur, the barge can not be moved back into the blast area due to the presence of the down tubes that run from the barge to the charges set along the bottom. Moving the blast barge into the area after it is "backed out" would likely entangle the down tubes which could result in an incomplete blast posing a significant safety hazard to both the crew and other vessels.

The charges were set off at approximately 2:17 pm and dead fish were observed floating in the blast zone. The fish observer estimated that approximately 1,000 small bait fish floated to the surface after the blast. He began to collect the fish for analysis and identification. Seagulls were feeding on some of the floating fish during the collection. The fish collected post-blast included 103 alewife, 18 blueback herring (*Alosa aestivalis*), 30 menhaden (*Brevoortia tyrannus*), 38 Atlantic herring (*Clupea harengus harengus*), 16 rainbow smelt, five cunner, and four red hake. The fish were then delivered to MA Division of Marine Fisheries (Ms. Tay Evans). Fish lengths and weights were also recorded and are included in Appendix B.

2. Discussion of a Possible Cause and Corrective Action(s) Taken

The resulting fish kill appears to be the result of a miscommunication between the fish observer and the Contractor who believed he needed to execute the blast within 10 minutes of the removal of the fish startle system from the area and not wait for an “all clear” from the fish observer. As a result of this blast event, the following changes to blast protocols were instituted to minimize the potential for additional fish kills:

- Fish Startle System: The Contractor is to deploy the fish startle system on an alternate and more mobile vessel instead of on the blast barge. This is to allow the fish startle system to remain operational and mobile in the blast area while the blast barge is being pulled back from the area to minimize potential "attraction" to the barge shadow. It will also allow the startle system to be redeployed to the area in the event blasting is not initiated since it will have the ability to enter the area so as to not impact down tubes.
- Dredging at Adjacent Areas: Dredging at adjacent areas will be curtailed if it is determined that it is the source of any detrital plumes impacting the blast area which could potentially be acting as an attractant to fish. Dredging would be allowed to continue only during portions of a tidal cycle that results in a plume trajectory away from the blast zone.
- Improved Communication: All parties will be clearly informed of communication pathways and roles and responsibilities relative to fish observance and blast initiation. It will be emphasized that it is the sole responsibility of the fish observer to give the “all clear” signal to initiate the blasting sequence based on fish observations. The fish observer would not signal for initiation of the blast sequence until he determined, through use of the side scan sonar and any other observations that there were no schools of fish present in the blast area. The only overriding condition would be the need to initiate the blast sequence for safety reasons as directed by the safety officer. One example would be when it would be necessary to initiate a blast sequence to comply with the “45minutes prior to sunset” provision. At this point blasting must be initiated due to safety considerations and to comply with safety regulations. All involved parties are to be made aware of these protocols and the need for clear and constant communication between the fish observer and the blast barge personnel.

It is also noted that the blasting safety officer reserves the right to override the fish observer in the event that a situation develops which could jeopardize human safety. The safety officer would communicate the reasons for the override to the fish observer prior to the initiation of the blast sequence which would be documented in both the blast report and the fish observer report. An additional overriding safety requirement is that once the blast sequence is initiated with the first five minute warning blast, the blast must continue according to safety regulations.

C. Fish Kill Number 3

1. Event Specifics

The third fish kill was observed after the 12th blast event on November 9, 2007. Normal sequencing protocols were followed which incorporated the corrective actions identified after the second fish kill event. The fish startle system was deployed at 3:38 pm and removed at 4:02 pm. Schools of fish were observed sporadically on the side scan sonar transiting through the area. The barge was moved 250 feet outside the blast area. Once it was determined that no fish were in the area, an “all clear” signal was given by the fish observer and the blasting sequence was initiated. Blasting occurred at 4:05pm,

approximately 45 minutes before sunset. The corrective actions implemented after fish kill #2 were implemented for this blast event.

After the blast, approximately 900 to 1,000 fish were observed floating on the surface. Less than 100 fish were collected with a dip net until no more fish were observed at the surface. As in previous events seagulls fed on the floating fish. The majority of the fish collected were blueback herring (80) and menhaden (14). The length, weight, and species of fish collected were recorded.

2. Discussion of a Possible Cause and Corrective Action(s) Taken

For safety reasons, blasting needed to be initiated 45 minutes before sunset. Although no fish were observed when the "all clear" signal was given by the fish observer, it is possible that because fish had been previously seen sporadically transiting the project area on the side scan, that some of these fish moved into the blast area after the "all clear" signal was given.

D. Fish Kill Number 4

1. Event Specifics

The fourth and last fish kill event occurred after the 13th blast event on November 14, 2007. Approximately 300 fish were observed floating or being eaten by the seagulls, far less fish than the last fish kill event. About one-fourth the amount of explosives was used for the third fish kill than was used for this blast event. Only six fish were collected, mainly due to gusty winds and wave action which carried the fish out of the area. All the fish collected were menhaden. Lengths and weights were recorded and presented in Appendix B.

2. Discussion of a Possible Cause and Corrective Action(s) Taken

As in Event #3, the corrective actions recommended after Fish Kill Event Number 2 were implemented during this event. The fish startle system was located on a separate boat, no dredge plume from adjacent dredging operations were observed in the area, and the blasting sequence was not initiated until after the fish observer has swept the area and had given an "all clear" signal.

After this event it was agreed that the Corps agreed would prepare an "After Action Report" to document the blasting operations and fish kill events to discuss lessons learned and possible recommendations for consideration in the development of a comprehensive blasting plan for the upcoming Boston Harbor Deep Draft Project.

E. Note

After the last blast event on December 5, 2007, it was noted that one fish, a menhaden (97 mm long and weighing 8 grams), was observed floating at the surface in the Broad

Sound North Channel. There were no other fish observed floating at the surface after the blast.

IV. Lessons Learned and Corrective Actions to be Instituted for Future Blast Events

Based on the events that occurred in 2007 during rock removal operations, the following recommendations should be considered for implementation for future blasting events.

A. Communication Plans

1. Fish Observer/Contractor Communication Plan

The contract specification on fish protection will clearly identify, with the exception of an overriding safety issue as identified in the previous sections, that it is the sole responsibility of the fish observer to determine when conditions are favorable for the blasting sequence to be initiated based on fishery observations. The fish observer will give approval for initiation of the blast sequence until s/he has determined, through use of appropriate technology, that no schools of fish are present in the blast area. However, it is recognized that the on-site safety officer has the authority and responsibility to override the fish observer's determination at those times when either safety concerns or regulatory compliance becomes an issue. The specifications will outline required protocol and the need for clear and constant communication between the fish observer and the blast barge personnel.

2. Fish Observer Reports

The fish observer will prepare an after action report for all blast events monitored, regardless of whether the event resulted in a fish kill. The report should include the date and time monitoring was initiated, deployment and retrieval of the fish startle system, the time of the blast, current speed and direction, tidal conditions, and weather observations throughout the day, and other pertinent observations. The fish observer will note if fish were observed in the project area prior to blasting and if there were any dead or injured fish after the blast. The fish observer must record the number of fish killed or injured, and species including representative sizes and weights. Any equipment or operational issues that may have contributed to the fish kill will also be noted.

The fish observer will report his/her findings to the Resident Engineer for each day of blasting. The Resident Engineer will compile the previous week's reports and forward to the Project Manager or Study Manager and the Environmental Resources Team Member. If a fish kill is observed, the Resident Engineer will notify the Project Manager or Study Manager and the Environmental Resources Team Member immediately. Pertinent information along with the fish observer's report will be forwarded to the above parties as soon as possible. Based on the fish observer's report, the Project Manager, or Study Manager, will convene a meeting with the Resident Engineer and appropriate personnel

to discuss events and to determine what, if any, corrective actions can be taken to reduce the changes of further fish kills.

3. External Communication Plan

In the event of a fish kill, the Project Manager or Environmental Team Member will notify the appropriate resource agencies as soon as possible after the event. Additional communication will occur as soon as all pertinent facts and issues surrounding the event have been determined. In the case of the Boston Harbor Deep Draft Project, the NMFS, U.S. EPA, MA DEP, MA DMF, MA Coastal Zone Management Office, and Massport will receive a copy of the fish observers report along with other factual information. If determined necessary, a meeting and/or conference call will be scheduled between the Corps, Massport, and the resource agencies to discuss and identify potential corrective measures. These measures will then be forwarded along with the fish observer report to the agencies.

B. Operational Changes to Minimize Potential for Fisheries Impact

The Contractor will deploy the fish startle system on an alternate vessel instead of the blast barge to allow greater coverage of the blast area and extend duration of the systems deterrence action just prior to blasting. This will allow the fish startle system to stay deployed in the blast area while allowing the blast barge to be pulled back from the area to minimize potential fish "attraction" to the barge shadow in the water column.

It is possible that a dredging plume may serve as an attractant to the fish towards the blast zone. Consequently, it is recommended that any dredging activities adjacent to the area of blasting occur when tidal conditions allow for the transport of resuspended material to move any residual plumes away from the blast area(s).

Additional conversation among the Corps, their blasting contractor, and the fish observer resulted in identifying some additional operational steps that could potentially be taken for future blasting events to help deter the presence of fish in the blast area. These included the use of setting off small charges in the blast area to "scare" the fish from the area or perhaps using bait to attract the fish to another area. After further discussion with the blasting contractor the use of small charges as a deterrent was dismissed since the blast is set off through a percussion process. Small charges could prematurely set of the blast for a percussion process which would constitute a significant safety hazard. Small charges can only be used when electric charges are used.

"Baiting" was another suggestion to draw fish away from the blast zone. However, it would likely act as an attractant for other fish and could make the situation worse. Also, since the target species (herring) are primarily planktonic feeders, appropriate bait was questionable.

V. Discussions for Development of a Blast Plan

In order to move the development of a formal blast plan for both the upcoming Boston Harbor Deep Draft Project and other similar type Corps projects forward, scheduled meetings should be held with the blast subgroup of the Technical Working Group for the Boston Harbor Deep Draft Project. This subgroup would identify blast issues that require further discussion, research, and resolution for incorporation into the plan. At a minimum, the following items should be included for discussion:

- Significance – What constitutes a significant fish kill and what would determine the need for corrective actions, and mitigative measures?
- Mitigation Measures and Operational Approaches – What are the available mitigation measures that can be incorporated into the blast plan? What approaches should be considered and incorporated into the dredge plan to minimize impacts to fisheries?
- Time of Year and Sequencing – Time of year and sequencing approaches based on the presence of fish resources should be explored with the resource agencies as a mitigative tool to minimize blasting impact to fishery resources.

Discussion with the resource agencies should occur to determine, based on the species of concern prevalent in the harbor, and the amount of rock to be blasted in the various harbor locations, what time of year blasting should occur in the harbor and in which location or tributaries.

C. Plan of Action for Fish in the Blast Zone

A discussion of alternatives, if any, should be considered for those times when the side scan sonar survey indicates large numbers of fish are in the blast zone throughout the day and the charges have been set. According to the fish observer (personal communication June 17, 2008), no fish were observed on the side scan sonar during the non-fish kill events. (The exception to this is the first fish kill; during this event, no smelt were observed on the sonar.) This would indicate that, in general, the sonar can and did detect schools of fish in the blast area. There may be days when a suitable time to initiate blasting is not available due to the presence of fish observed in the blast area. Alternatives, if available, should be explored when this condition arises. Safety may dictate that blasting will need to be initiated, even if there are schools of fish in the area.

APPENDIX A

Table A-1. Number and Fish Species Collected By Blast Date

Common Name	Latin Name	Fish Kill Dates (2007)			
		October 24	October 29	November 9	November 14
Alewife	*Alosa pseudoharengus*	2	103		
Atlantic Herring	*Clupea harengus harengus*				
Blueback Herring	*Alosa aestivalis*			80	
Butterfish	*Peprilus triacanthus*	1			
Cunner	*Tautogolabrus adspersus*	23	5		
Menhaden	*Brevoortia tyrannus*			14	6
Rainbow Smelt	*Osmerus mordax*	124	16		
Red Hake	*Urophycis chuss*	3	4		
Total Number of Fish Collected		**153**	**214**	**94**	**6**

APPENDIX B

Table B-1. Length and Weight of Fish Species Collected October 28, 2007

Alewife		Atlantic Herring		Blueback Herring		Cunner		Menhaden		Rainbow Smelt		Red Hake	
L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)
135	18	138	20	123	17	58	3	98	8	103	5	92	4
157	28	118	11	139	19	55	2	99	9	105	6	80	3
145	26	136	18	155	27	75	8	100	9	125	10	72	2
142	22	158	25	143	22	53	2	102	7	135	14	62	1
137	20	143	22	127	14	38	1	100	11	117	8		
167	37	160	30	120	12			99	10	105	6		
138	19	140	20	125	13			92	7	111	8		
153	29	156	30	137	18			82	5	120	8		
167	38	140	21	143	17			83	7	92	4		
226	94	150	22	120	12			95	7	123	11		
146	23	152	22	119	11			92	8	100	5		
147	24	152	28	117	12			102	11	127	11		
194	70	150	26	137	19			95	7	130	12		
135	19	170	40	141	20			100	9	115	9		
146	26	182	43	120	13			100	9	111	7		
1X*	17	160	30	132	18			81	7	112	7		
167	40	143	23	139	20			85	5				
150	26	152	24	120	13			100	9				
156	27	136	20	122	13			98	8				
148	26	169	33					85	6				
130	17	150	24					110	13				
145	25	134	27					92	7				
145	25	138	20					93	8				
139	20	177	41					113	13				
132	18	162	33					89	6				
150	23	165	34					88	7				
150	26	140	18					100	10				
160	32	130	17					92	7				
145	30	145	21					93	7				
169	39	148	24					100	9				
144	23	140	20										

*1X = No Tail

Table B-1 (cont.). Length and Weight of Fish Species Collected October 28, 2007

Alewife		Atlantic Herring		Blueback Herring		Cunner		Menhaden		Rainbow Smelt		Red Hake	
L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)
155	27	141	20										
150	27	142	22										
135	20	158	30										
145	22	138	20										
138	19	144	24										
153	28	150	25										
153	32	128	16										
152	28												
177	40												
138	20												
157	32												
148	24												
162	32												
130	17												
133	19												
165	36												
145	23												
158	30												
135	18												
135	20												
157	32												
142	21												
134	18												
150	26												
157	29												
136	20												
156	27												
155	30												
141	20												
155	29												
137	19												
158	34												

Table B-1 (cont.). Length and Weight of Fish Species Collected October 28, 2007

Alewife		Atlantic Herring		Blueback Herring		Cunner		Menhaden		Rainbow Smelt		Red Hake	
L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)
149	25												
142	23												
171	38												
149	23												
158	31												
143	23												
138	22												
129	17												
151	27												
156	29												
155	29												
155	29												
135	20												
168	37												
139	20												
135	17												
156	27												
177	45												
138	20												
157	28												
140	22												
129	16												
161	31												
161	35												
152	28												
130	17												
167	36												
139	20												
147	24												
147	25												
148	24												
145	23												

Table B-1 (cont.). Length and Weight of Fish Species Collected October 28, 2007

Alewife		Atlantic Herring		Blueback Herring		Cunner		Menhaden		Rainbow Smelt		Red Hake	
L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)	L (mm)	W (g)
145	24												
150	25												
166	33												
149	25												
173	40												
150	26												
142	21												
128	16												

Table B-2. Length and Weight of Fish Species Collected November 9, 2007

Blueback Herring				Menhaden	
Length (mm)	Weight (g)	Length (mm)	Weight (g)	Length (mm)	Weight (g)
99	7	102	8	75	4
100	7	94	6	108	12
89	5	93	6	96	9
93	6	88	5	83	6
98	7	98	6	70	4
90	5	94	6	61	2
95	6	100	7	70	3
103	8	97	7	64	2
93	6	92	6	81	5
94	6	93	6	54	2
97	8	97	7	80	5
95	8	97	7	60	2
113	11	90	6	59	2
105	9	93	6	57	2
96	8	97	7		
101	9	96	6		
108	10	106	9		
90	6	87	5		
98	7	104	9		
103	9	92	6		
96	6	88	5		
99	7	104	8		
104	8	94	7		
85	5	98	7		
95	7	96	7		
93	6	99	7		
103	8	100	8		
101	7	90	6		
113	10	91	5		
94	6	90	5		
94	6	97	7		
96	7	94	5		
108	9	90	6		
92	6	91	6		
96	7	85	5		
90	6	99	7		
100	7	96	7		
92	6	99	7		
91	6	110	9		
90	6	99	7		

Table B-3. Length and Weight of Fish Species Collected November 14, 2007

Menhaden	
Length (mm)	**Weight (g)**
90	6
62	2
50	1
61	2
51	1
65	3

ATTACHMENT G

Method of Operation and Communication

The following is a generic blasting sequence to give a general idea of the procedures associated with drilling and blasting. The information below should not be considered the blasting plan for the New Bedford Marine Commerce Terminal. Actual methods and sequences will be outlined in the Blasting Plan that will be submitted in accordance with Specification Section 02900.

Preparation for Drilling & Blasting

- Using the approved transfer procedure, take on board the regulatory approved allowable product quantity for storage.
- The blasting engineer shall log in the coordinates and/or feet on deck for the site specific range(s) of the holes and record on the Frame Logs.
- Position the Drillboat and verify tide, depth of water, overburden, and top of rock.
- When drilling near or adjacent to a loaded hole, drilling shall be limited to vertical holes only.
- Record the data on the Frame Log and proceed with drilling to "site specific" elevation (tide corrected) or as directed by the Blaster-in-Charge.
- Should competent rock exist above required grade elevation, proceed with drilling and loading in preparation for blasting.

Drilling Method

- Complete drilling and verify a loadable hole using a continuous monitoring Angle Indicator to assure the tower does not deviate during the drilling process.
- If the drill steel can be extracted without encountering any obstacles, the loading procedures may begin.
- Should the hammer have to be rotated or used to extract the drill steel, additional cleaning of the hole by making additional drill passes will be used to assure a loadable hole.
- Once the drilling and cleaning of the hole has been completed, the boosters will be prepped while the drill steel is being removed from the hole and secured to the steel rack or tower frame.
- Primers and/or charges will not be removed from the day boxes and taken out on the catwalk/drill platform until the hole is ready to load.

Loading Method

- Consult the applicable loading schedule for product versus feet of rock.
- Prepare the primer assembly for each booster location in the blast hole using the in-hole detonator and a Booster.
- Install the primer assemblies and the main explosives charge in the hole, using a measuring device to seat the explosives column and to verify the elevation of top of product.
- Install the stemming bag to seal the collar of the hole.
- Upon completion of loading of a blast hole, the initiation down lines will be recovered and secured to the shot line. Down lines will be secured with adequate slack to compensate for tidal fluctuations and setbacks. Once charging of the entire range (row of holes) has been completed, the down lines will be connected using the appropriate surface delays between holes. All surface connections will be done in duplicate to ensure

redundancy of the initiating sequence. Be aware of the directional initiation path and confirm that all surface delays are connected in the proper direction.

- Upon completion of the first range and with all connections made, the Drill boat will set back and be located with the first hole on deck located over the desired position in the second range.
- Holes will be drilled and loaded sequentially according to the Production Blast Plan.
- When charging of the second range has been completed, the same connection procedure as above will be followed. Connections between ranges (rows) will be made using the appropriate surface delay time as per the blast design.

Preparing to Blast

- At a suitable time before the planned blasting time as determined by the Blaster in-Charge, two lead-in assemblies will be connected to the appropriate position to initiate the blast. The shock tube section of this lead-in line will be secured to a rope.
- The lines will be lowered into the water and will be supported by buoys.
- The rope and lead-in lines will be paid out as the Drillboat retreats to its safe blasting position.

Clearance Prior to Blasting

- At the appropriate time, but no later than noontime on any given day, the 2-hour Notice to Blast will be given and the Window of Opportunity will commence (more detail on the Window of Opportunity follows below). Verify with the Fisheries Observer (approved by Massachusetts Division of Marine Fisheries and National Marine Fisheries Services) that no schools of fish are present.
- Verify with the Vibration Consultant that all seismic stations are online prior to tying in the lead-in line which will be utilized to initiate the blast.
- At the 1-hour Notice to Blast: Verify with the approved Fisheries Observer that no schools of fish are present.
- At the 15-minute Notice to Blast: Verify with the Fisheries Observer that no schools of fish are present. Receive "ok to blast" notification from approved Fisheries Observer. In the event that the Fisheries Observer notifies Cashman Weeks NB that schools of fish or are present, the blasting procedure will be delayed until the schools of fish move from the area. Notifications will be made to the Pre-Blast Call List that the blast is delayed and the notification procedure will restart with the 1-hour Notice to Blast. This procedure will continue until the Fisheries Observer gives the "ok to blast" but at no time will exceed 4:00 pm of any day due to Project and Public safety.
- At the 15-minute Notice to Blast: the Drillboat must retreat to its safe position and the security patrol boats are positioned for enforcement of the Safety Zone.
- Verify an All CLEAR TO BLAST of personnel working in the area from both land and marine safety stations.
- Proceed with the 5-minute warning with an ALL CLEAR TO BLAST from the security patrol boats.
- The last 10 seconds of the 1-minute warning will be broadcast on CH16 beginning with 10. Counts 3 and 2 will be silent with all radios un-keyed allowing any Safety Zones to "Abort" the blast.
- ***SIGNAL and DETONATE***

- Give ALL CLEAR signal.

The Window of Opportunity is defined as follows:

- A two-hour notice of intent to blast with a thirty minute grace period before or after the two hours has passed.
- Should complications prevent blasting within the Window of Opportunity, the two-hour notice of intent must be updated.
- The necessary notifications within the Window of Opportunity are as follows:
- 2 hour notice – (see Pre-Blast Call List)
- 1 hour notice – (see Pre-Blast Call List)
- 15 minute warning CH16, Drillboat Channel
- 5 minute warning CH16, Drillboat Channel, Audible Blast Signal
- 1 minute warning VTS, CH16, Drillboat Channel, Audible Blast Signal
- Countdown – CH16, Drillboat Channel
- ***Blast***
- ALL CLEAR Drillboat Channel, Audible Blast Signal

Note 1: Because of the marine environment and potential intrusion of traffic into the safety zone, the 15-minute and 5-minute warning may be accelerated. However, the 1-minute warning must be completed.

Note 2: Throughout the drilling and loading procedure, constant monitoring of fish schools shall be performed by an approved Fisheries Observer.

Note 3: There shall be no blasting during the passage of schools of fish are present as determined by the approved Fisheries Observer unless it is determined that there is a threat to Project and Public safety.

Blast Signals

A horn with 120 dB minimum as measured at the perimeter of the blast area zone will be utilized to produce blasting signals as below. The sound will be distinctly different from any emergency signal which may be utilized on board the Drillboat.

<u>WARNING SIGNAL</u>

1 minute series of long wails 5 minutes prior to blast signal.

<u>BLAST SIGNAL</u>

A series of short yelps 1 minute prior to the shot.

<u>ALL CLEAR SIGNAL</u>

A prolonged horn signal following the inspection of the blasting area.

Pre-Blast Call List

A list of contact information (Pre-Blast Call List) will be used for notification prior to a blasting event taking place. This list will be developed in preparation for the drilling and blasting work effort and the final version will be provided to the Owner's Representative prior to the start of any blasting activity.

The following parties (not a comprehensive list) are anticipated to be contacted or request to be contacted at the time required by each party prior to blasting:

- US Coast Guard
- New Bedford Police Department
- Fairhaven Police Department
- US Army Corps of Engineers
- Owner Representative's project office
- Vibration Consultant
- Fisheries Observer

An example of the Pre-Blast Call List used on a US Army Corp of Engineers is shown on the next page.

Pre-Blast Call List

Blast No.: _____ **Drill Boat:** **Kraken**

New York and New Jersey Harbor
Channel Navigation Improvement
S-NB-2 / S-AK-1 - Contract 11
W912DS-10-C-0023

Caller: _____ Day: _____ Date: _____ Sheet: _____ of _____

	2 HOUR		1 HOUR		15 MIN		ALL CLEAR	
	NAME NOTIFIED	Callers Initials	NAME NOTIFIED	Callers Initials	NAME NOTIFIED	Callers Initials	NAME NOTIFIED	Callers Initials
USCG Activities New York (718) 354-4088 (718) 354-4096 (fax)								
					5 MIN (USCG only)		**1 MIN (USCG only)**	
US Army Corps of Engineers (201) 433-9232								
The Port Authority of NY & NJ Port Newark Operations (OCC) (973) 578-2192								
Bayonne Police & Fire Depts. (201) 858-6900								
Newark Fire Department (973) 733-7400								
Elizabeth Fire Department (908) 820-2800								
Staten Island Fire Departmen (718) 494-4296								
Mike V. (Diving Contractor) (856) 207-4952 **Divers Clear At:**								
Contract Drilliing & Blasting LLC (201) 339-6470			**2 Hour and All Clear Only**					
Randive, Inc (732) 324-1144			**2 Hour and All Clear Only**					
Richard Nolen-Hoeksena (203) 907-8586 (E4 Sciences)			**2 Hour and All Clear Only**					
snb_vibrations@e4sciences.com	**Blast Number, Blast Time, Northing, Easting**							

2 Hour Warning Time: _____

1 Hour Warning Time: _____ **<--Call Security Boats**

15 Minute Warning Time: _____

5 Minute Warning Time: _____

Time of Blast: _____

Time of All Clear: _____

Number of Holes: _____

Security Calls on Ch 13 & 78

Radio 2 Hour: _____

Radio 1 Hour: _____

Radio 15 Min: _____

Radio 5 Min: _____

Radio 1 Min: _____

Count Down: _____

All Clear: _____

BLAST WINDOW **from:** _____ **to:** _____

Blaster Name: _____ Blaster License No. _____

Caller Signature: Date: