MASSACHUSETTS BAY DISPOSAL SITE RESTORATION DEMONSTRATION REPORT 2008–2009

December 2015

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13. ABSTRACT
A restoration demonstration project was conducted at the Massachusetts Bay Disposal Site (MBDS) between 2008 and 2009 by the U.S. Army Corps of Engineers New England District's Disposal Area Monitoring System (DAMOS) Program. The overall goal of the demonstration was to evaluate methods for the potential use of dredged material to restore the adjacent Industrial Waste Site (IWS).

Beginning in 1952, the IWS was designated as an approved low level radioactive waste (LLRW) disposal site. Previous investigations estimated that approximately 20,000 barrel-like containers are exposed on the seafloor of the IWS and visual inspection of these targets showed that the majority of the barrels were punctured, open, or deteriorated with the contents exposed to the environment. Despite the presence of a large number of damaged waste barrels no sediment or tissue samples collected at the IWS have shown elevated levels of radioactivity, however, the potential risk for environmental exposure of LLRW as the containers continue to deteriorate has led to the goal of implementing a restoration plan for the site. The 2008–2009 project was a demonstration scale operation utilizing Boston Blue Clay from a Boston Harbor dredging project to determine if a sequenced approach to placement would minimize disturbance to waste containers and potentially contaminated in-place sediments if a restoration effort was attempted at the IWS.

In 2008 approximately 380,000 m^3 of Boston Blue Clay and glacial till was deposited in a demonstration area of MBDS to test the restoration concept. The material was placed in several different disposal strategies including individual placements on the ambient seafloor, placements on small berms of dredged material, and multiple overlapping placements. Regular monitoring surveys were conducted between disposal phases to document placement accuracy, berm formation, and disturbance to in-place sediments.

The project demonstrated that standard operational procedures could be utilized to accurately place dredged material at MBDS without interfering with dredging schedules or budgets. Analysis of dredged material deposits placed directly on the ambient seafloor showed scouring and mixing of the in-place sediments as a result of the impact process. Similar sized placement events directed to an area covered by a berm of previously placed dredged material showed evidence of disturbance to the berm deposit but not to the underlying ambient sediments.

The restoration demonstration project established that accurate, sequential placement of dredged material could be achieved at MBDS without increasing the costs of a dredging project. The experiment also demonstrated that a sequential approach to placement could effectively protect the in-place sediments and waste containers from impact forces and develop a cover layer over the containers. Data generated through this demonstration project could be used to design a full-scale restoration approach for the Industrial Waste Site and eliminate the long term potential environmental and human health risk posed by the LLRW containers still exposed at the site.

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<u>Note on units of this report</u>: As a scientific data report, information and data are presented in the metric system. However, given the prevalence of English units in the dredging industry of the United States, conversions to English units are provided for general information in Section 1.

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EXECUTIVE SUMMARY

A restoration demonstration project was conducted at the Massachusetts Bay Disposal Site (MBDS) between 2008 and 2009 by the U.S. Army Corps of Engineers New England District's Disposal Area Monitoring System (DAMOS) Program. The overall goal of the demonstration was to evaluate methods for the potential use of dredged material to restore the adjacent Industrial Waste Site (IWS).

The IWS is an area of Massachusetts Bay that has been historically used for the offshore disposal of waste including dredged material, construction debris, munitions, and hazardous waste. Beginning in 1952, the IWS was designated by the Atomic Energy Commission (AEC) as an approved low level radioactive waste (LLRW) disposal site. The single AEC licensed contractor (Crossroads Marine Disposal) collected LLRW from hospitals, laboratories, and universities; sealed the waste into 55 gallon drums encased with a 4–6 inch concrete liner; and disposed the drums at the IWS. AEC records indicate that approximately 4,000 containers of LLRW were disposed at the IWS before offshore disposal operations ceased in 1959; although pre-1952 disposals, and additional undocumented disposals, suggest that the actual number was likely much higher.

Due to the LLRW disposal history at the IWS, the site has been the subject of numerous investigations since the 1970's. Field surveys included underwater video, side-scan sonar, remote operated vehicles, manned submersibles, sediment sampling, and tissue sampling of fish and invertebrates. Side-scan sonar investigations estimated that approximately 20,000 barrel-like containers are exposed on the seafloor of the IWS, and visual inspection of these targets showed that the majority of the barrels were punctured, open, or deteriorated with the contents exposed to the environment. Despite the presence of a large number of damaged waste barrels, no sediment or tissue samples collected at the IWS have shown elevated levels of radioactivity; however, the potential risk for environmental exposure of LLRW as the containers continue to deteriorate has led to the goal of implementing a restoration plan for the site.

This restoration demonstration project was developed in cooperation with the U.S. Environmental Protection Agency (EPA) Region 1 to enable a rare opportunity to cover the historic IWS using of a large volume of sediment (about 12 million yds^3/9.2 million m^3) that will be dredged from deepening Boston Harbor, possibly starting in late 2016. The available dredged material will be primarily Boston Blue Clay, a highly consolidated glacio-marine deposit, which would otherwise be placed via split-hull barges at MBDS. The 2008–2009 project was a demonstration scale operation utilizing Boston Blue Clay from another Boston Harbor dredging project to determine if a sequenced approach to placement would minimize disturbance to assumed fragile waste containers and potentially contaminated in-place sediments if a restoration effort was attempted at the IWS.

The demonstration was performed in a portion of MBDS with no known waste containers but with a similar water depth, currents, and bottom type to the IWS. The plan involved precise placement and sequencing of disposal operations in an attempt to build a berm of dredged material that would spread laterally into the target area with minimal disturbance of the existing bottom sediments. Subsequent placement events would occur over the berm itself, utilizing the protective berm layer to buffer the in-place sediments from the energy of a direct impact. In order for the proposed process to be practical the demonstration also had to prove that the restoration could be implemented without increased cost or time to the dredging operation.

In 2008 approximately 380,000 m^3 (500,000 yds^3) of Boston Blue Clay and glacial till was deposited in a demonstration area of MBDS to test the restoration concept. The material was placed in several different disposal strategies including individual placements on the ambient seafloor, placements on small berms of dredged material, and multiple overlapping placements. Regular monitoring surveys were conducted between disposal phases to document placement accuracy, berm formation, and disturbance to in-place sediments through multibeam bathymetry, side-scan sonar, acoustic backscatter, sub-bottom profiling, and sediment-profile imagery. A sediment coring survey was conducted in 2009 following the completion of all disposal events.

The project successfully demonstrated that standard operational procedures could be utilized to accurately place dredged material at MBDS without interfering with dredging schedules or budgets. Placement accuracy averaged 62 meters between the target point and the disposal crater which was within the scale of the split-hull barges used for disposal.

Individual disposal events of 4,000–4,500 m^3 of Boston Blue Clay formed circular craters on the ambient seafloor approximately 0.1–1.1 m deep and 60–100 m across with a defined rim surrounded by a thin berm. The berm extended several hundred meters from the impact point and gradually tapered from 0.5–0.1 m thick. Disturbance to the in-place sediments beneath the impact craters was assessed through an analysis of acoustic and sediment coring data and suggested that substantial (> 35 cm) scouring and mixing of the ambient seafloor occurred as a result of the placement process.

Similar sized placement events that were directed to an area covered by a thin (0.3 m thick) berm of dredged material formed craters that were comparatively shallower and wider than the craters formed over ambient sediments suggesting that the berm deposit was successful in absorbing some of the direct impact energy and transferring it in a horizontal direction. Analysis of acoustic and sediment coring data from these craters supported this finding as there was evidence of disturbance to the berm deposit but not to the underlying ambient sediments.

The restoration demonstration project established that accurate, sequential placement of dredged material could be achieved at MBDS without increasing the costs of a dredging project. The experiment also demonstrated that a sequential approach to placement, beginning operations outside of the barrel field to build a protective berm followed by placements on the berm deposit, could effectively protect the in-place sediments and waste barrels from impact forces and develop a cover layer over the barrels. Data generated through this demonstration project could be used to design a full-scale restoration approach for the Industrial Waste Site and eliminate the long term potential environmental and human health risk posed by the LLRW barrels still exposed at the site.

1.0 INTRODUCTION

A restoration demonstration project was conducted at the Massachusetts Bay Disposal Site (MBDS) between 2008 and 2009 by the U.S. Army Corps of Engineers New England District's Disposal Area Monitoring System (DAMOS) Program. The overall goal of the demonstration was to evaluate methods for the potential use of navigation-project dredged material in restoration of a nearby area (Industrial Waste Site or IWS) that historically received a combination of industrial wastes, low-level radioactive wastes (LLRW), munitions, and debris in addition to dredged material. An introduction to the DAMOS Program and brief overview of the restoration demonstration are provided below in Section 1. Background on the historical IWS is provided in Section 2, and background on the history of use and placement of cap material at aquatic sites is provided in Section 3. The methods and results of the restoration demonstration are provided in Sections 4 and 5, respectively. Additional collection of background information at the historical disposal site was performed by the U.S. Environmental Protection Agency (EPA) in 2006 and 2010 and is presented in Section 6. Discussion and conclusions related to the restoration demonstration and the potential application of the restoration approach at the IWS presented in Sections 7 and 8.

1.1 Overview of the DAMOS Program

For over 35 years, the DAMOS Program has conducted monitoring surveys at aquatic disposal sites throughout New England and evaluated the patterns of physical, chemical, and biological responses of seafloor environments to dredged material disposal activity (Fredette and French 2004, Wolf et al. 2012). Primary survey techniques include precision bathymetry and sediment-profile imaging; with additional acoustic, imaging, and sample collection techniques included as needed. The collected data are used to confirm the accurate placement of dredged material at sites and to track the biological recovery of sites following placement, supporting the primary goal of the program in long-term management of aquatic placement of dredged material. Survey data are reported in technical contributions available on the DAMOS Program website:

http://www.nae.usace.army.mil/Missions/DisposalAreaMonitoringSystem(DAMOS).aspx

In addition to this primary management goal, the program has historically contributed to the development of dredged material placement and restoration techniques. More focused material placement techniques can minimize impacts to existing benthic habitat and maximize the capacity at specific placement sites. The restoration method demonstrated in this project utilizes a subaqueous containment method which uses material determined suitable for open-water disposal, to overlay deposits of material with chemical or physical properties that benefit from isolation from the surficial benthic habitat and overlying water column (Fredette 1994). The use of suitable sediment to isolate deposits of unsuitable material was first introduced as a specific management technique in the DAMOS Program during the 1978–79 disposal season in Long Island Sound (SAIC 1995a) and has continued at multiple sites throughout New England. Additional information on previous investigations supporting this method of restoration is provided in Section 3.

1.2 Motivation for the Restoration Demonstration

The restoration demonstration project was developed in cooperation with EPA Region 1 to enable a rare opportunity to cover the historic IWS using of a large volume of sediment (about 12 million yds^3/9.2 million m^3) that will be dredged from deepening Boston Harbor, possibly in late 2016.

While conventional "capping" at MBDS is prohibited through the site designation and management regulations [40 CFR §228.15(b)(2)(vi)] this project would opportunistically utilize the Boston Harbor material to cover an existing environmental and human health exposure risk at the IWS. This represents the restoration of a historically contaminated site with material suitable for open water disposal at MBDS, not the disposal and capping of new contaminated sediments as prohibited in the regulations.

Taking advantage of this sediment availability is an opportunity to cover this historic waste disposal area and, if the opportunity is not taken, there is little likelihood of addressing the exposed waste at the IWS in the future. This perspective is supported by three facts: (1) previous investigations at the IWS did not identify existing unacceptable human health or environmental risks sufficient to initiate a remediation effort (see Section 2.2), (2) the site is relatively far from shore, relatively deep, and "out of sight, out of mind", and (3) if undue risks were ever identified at the site the costs of remediation would be large, and it is unlikely that a principle responsible party could be identified to fund the remediation.

As a consequence of these facts, it is exceedingly unlikely that any Federal, State, or local source of funds will ever be directed to the IWS. Nonetheless, given some uncertainty on the types of materials and their volumes placed at the IWS over its four decades of use (see Section 2.1), there is a lingering, though largely unsubstantiated concern regarding the risks that are present with the most likely being the accidental retrieval of waste containers by fisherman and the long term exposure potential to the ecosystem as the waste containers fail over time. If the available sediment from Boston Harbor can be used for restoration without adding cost to the dredging project, restoration of the site would be economically feasible and the lingering concern could finally be put to rest. However, if the restoration project begins to impact the budget or schedule of the dredging project, which has no legal or fiscal authority to expend funds on such a remediation effort, the opportunity to restore the area will be lost as the dredging project will default to using the preferred, existing Massachusetts Bay Disposal Site. This stark reality means that for the restoration project to occur it will have to work within the constraints of the dredging operation as the restoration project has virtually no budget other than in-kind agency support and the investigations described here-in.

The challenge of the demonstration, therefore, became (1) can a site restoration approach be developed that minimizes in-place sediment disturbance and (2) uses the standard disposal approach of a navigation dredging project?

The 2008/2009 restoration demonstration project was conducted by the DAMOS Program using sediment from another Boston Harbor project that generated sediments similar to those that will come from the proposed deepening project. That is, sediments underlying Boston Harbor that were deposited during the last glacial era (about 12,000 years before present) and consist of a range of glacial tills, clays, and sands. In a similar vein, the restoration demonstration used the 2008 dredging project opportunistically. While the studies described here had the broader goal of developing restoration approaches to be used at MBDS and other disposal sites, the IWS restoration project acted as a motivator to conduct the studies.

1.3 Project Overview and Objectives

The overall project objective was to test the feasibility of using sediments from a future Boston Harbor deepening project to help isolate historic sediments and waste containers at the IWS from environmental exposure. In order to test the feasibility of such a project, a restoration demonstration was performed at MBDS using sediment from another Boston Harbor dredging project. A series of surveys were conducted to address the following objectives:

- Assess the ability to accurately place dredged material using standard scow transport and release operations;
- Document the distribution and thickness of restoration material placed over the demonstration area;
- Assess the impact of the disposal process on the existing ambient seafloor sediments; and
- Assess any differences of impact disturbance between disposal events placed directly on the existing Massachusetts Bay seafloor and those disposal events placed on sediments where a disposal berm was established first.

2.0 BACKGROUND ON DISPOSAL IN MASSACHUSETTS BAY

Massachusetts Bay is accessible from Boston Harbor as well as other industrial harbors along the Massachusetts coastline and has been historically used for the offshore disposal of waste. Since the 1940's, disposal of industrial and commercial waste has been concentrated in an area of the Bay approximately 31 km (19 miles) from Boston Harbor (Figure 2-1). Part of this area was initially known as the Industrial Waste Site (Curtis and Mardis 1984, Keith et al. 1999).

2.1 Disposal History

Disposed materials at the IWS ranged from construction debris and dredged materials to munitions and hazardous waste including metallic sodium, neutralized acids, and halogenated organic compounds (Wiley et al. 1992, NOAA 1996). In 1952, the IWS was designated as an approved low level radioactive waste (LLRW) disposal site by the Atomic Energy Commission (AEC). It was believed that the waste containers would sink into the deep layer of soft sediment and be buried by subsequently accumulated sediments in this depositional area of the Bay (Curtis and Mardis 1984). Pre-license disposal of LLRW may have occurred in the Bay as far back as 1946 (Curtis and Mardis 1984, Figure 2-2). The LLRW disposed at the IWS was academic, commercial, and medical by-products that included glassware, clothing, ashes, lab equipment, and tools (Keith et al. 1999, Lockwood et al. 1982). Low level radioactive waste, by definition, excludes material involved in the processing of reactor fuel and weapons grade material (Curtis and Mardis 1984, NOAA 1996).

The sole licensed radioactive waste disposal contractor for the IWS (Crossroads Marine Disposal) typically sealed the LLRW in 5, 30, or 55 gallon containers that were encased in a four to six inch reinforced concrete liner (Curtis and Mardis 1984). The wet concrete was inscribed with the contractor name, date of encasement, prevalent isotope, surface radiation, and total activity level of the package (Curtis and Mardis 1984). This encasement technique was expected to withstand the corrosive marine environment and pressure of the disposal site for more than 800 years (Janes 1981). After several days of curing, the containers were transported by barge and tugboat to the disposal location by heading and distance navigation (prior to 1952) and, in later years, to a fixed Coast Guard buoy.

The AEC estimated from disposal records and interviews with the disposal contractor that approximately 4,000 containers of LLRW were deposited at the IWS between 1946 and 1959. This number may be a conservative estimate due to poor record keeping, non-permitted disposals before 1952, and a lack of information on classified material potentially disposed at the IWS (Wiley et al. 1992). After 1959, Crossroads Marine Disposal transported all LLRW to established land disposal sites. Permitted disposals of hazardous material and industrial waste continued at the IWS until 1976 (NOAA 1996).

In 1977 an area adjacent to the IWS was established by the EPA as the Foul Area Disposal Site (FADS), from that point forward only permitted dredged material was allowed to be placed at the site (Figure 2-2 and 2-3). In 1992 the FADS boundary was redefined to avoid the northern portion of IWS and renamed the Massachusetts Bay Disposal Site (DeAngelo and Murray 1997, Figure 2-3). The current site is configured as a circle, 3.7 km in diameter, centered at 42° 25.106′ N, 70° 34.969′ W (NAD 83). MBDS has water depths ranging from 82 to 92 m, and provides a 10.75 km^2 (3.14 nmi^2) area of seafloor in Massachusetts Bay for the placement of sediment suitable for unconfined open water disposal.

2.2 Investigation Summary

A number of studies have documented the presence of barreled waste containers at the IWS through side-scan sonar and remotely operated vehicle (ROV) surveys (Table 2-1). One survey found the barreled waste containers to be concentrated in the northern portion of the IWS with some isolated targets as much as 4.5 km outside of the currently defined boundaries of the IWS (Wiley et al. 1992). The authors estimated that approximately 20,000 barreled containers remained exposed at the IWS based on side-scan sonar data results. ROV images from the same study indicated that 75% of the investigated barrels were broken or damaged and 33% of the open containers showed evidence of being punctured prior to disposal (Wiley et al. 1992). The site was resurveyed by EPA in 2006 and again in 2010; results from these side-scan efforts are presented separately in Section 6.

In addition to identifying the location of the barreled waste containers at the IWS, several studies have measured radiation levels in locally collected sediment and tissue samples (Table 2-1). Curtis and Mardis'(1984) analysis of IWS sediment and biota revealed radiation levels of man-made nucleotides at or below accepted background levels in all samples including sediment, pelagic and demersal fauna, and commercial seafood species. Of the radionucleotides analyzed, only ^{137}Cs was found at significantly higher concentrations in IWS samples compared to samples collected from a reference area. However, concentrations of ^{137}Cs in IWS samples were below published background levels.

In 1992 a joint investigation of the IWS was conducted by EPA, National Oceanographic and Atmospheric Administration (NOAA), U.S. Food and Drug Administration (FDA), U.S Department of Energy (DOE), and the Commonwealth of Massachusetts. In addition to collecting sediment samples for analysis, the study also included the use of a ROV and a manned submersible equipped with a portable spectrometer capable of making in-situ measurements of radiation levels (Keith et al. 1999). Results from both in-situ measurements (within 1 m of waste barrels) and laboratory analysis of sediment samples found no evidence of man-made radionucleotides in the sediments surrounding the investigated barrels (NOAA 1996, Keith et al. 1999).

The 1992 study also included the analysis of sediment and tissue collected at the IWS for potential chemical contamination resulting from years of hazardous waste disposal at the site; including pesticides, polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and metals. The chemical concentrations detected in all tissue samples were within FDA guidelines for human consumption with the exception of two lobster tomalley samples that exceeded PCB tolerances (NOAA 1996). Sediment analyses from the same study showed organic compound concentrations similar to reference areas but elevated levels of certain inorganics (antimony, beryllium, calcium, cobalt, and cyanide) compared to reference sites (NOAA 1996). The authors concluded that biological and sediment contamination in the Bay from hazardous waste disposed at the IWS was uncertain (NOAA 1996).

Despite the documented analytical results of no definitive contamination, public and congressional concern over the potential human health and environmental risks associated with LLRW disposed at the IWS remain due to the relative shallowness of the site and its proximity to shore, commercial fishing grounds, and the Stellwagen Bank Marine Sanctuary (Figure 2-1). Since the 1960s there have been several anecdotal accounts and three documented instances of the retrieval of concrete lined containers by local fishermen in Massachusetts Bay (NOAA 1996, Keith et al. 1999). An interest in addressing these concerns led to the development of this demonstration project to potentially cover IWS sediments and barrels with opportunistically available material from Boston Harbor.

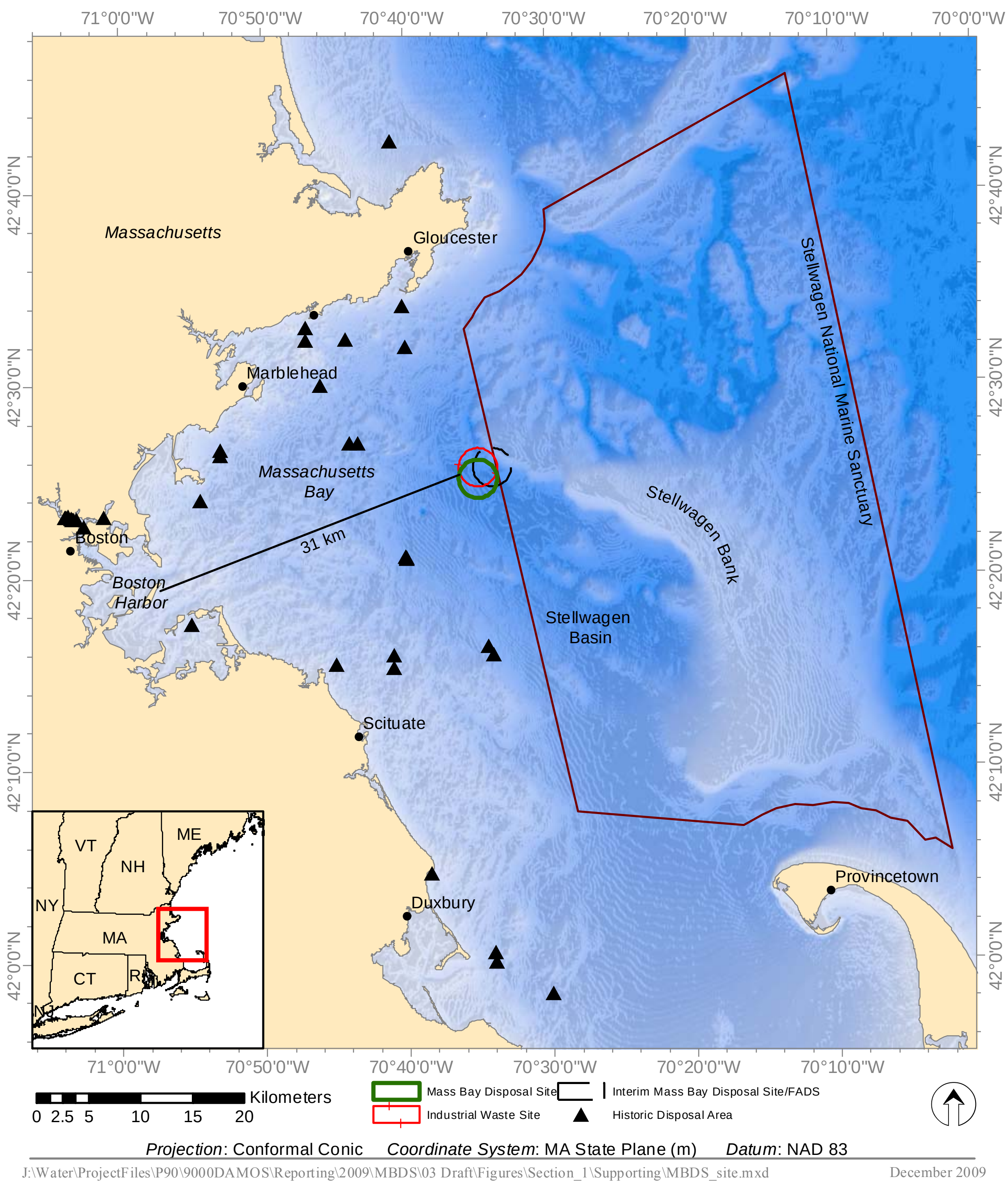

Figure 2-1: Location of the Industrial Waste Site in Massachusetts Bay

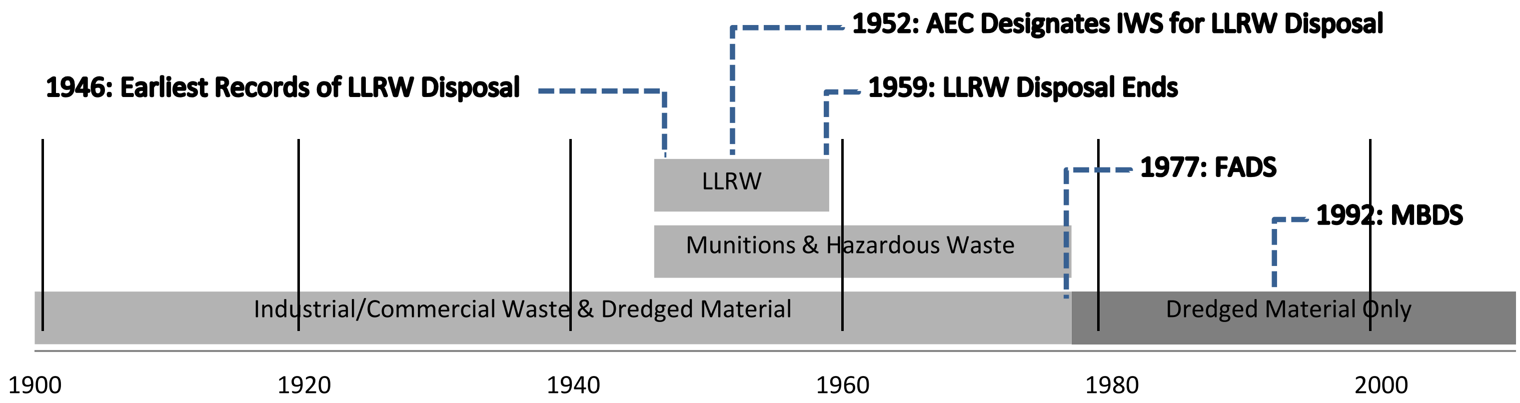

Figure 2-2: History of disposal at the IWS, FADS, and MBDS

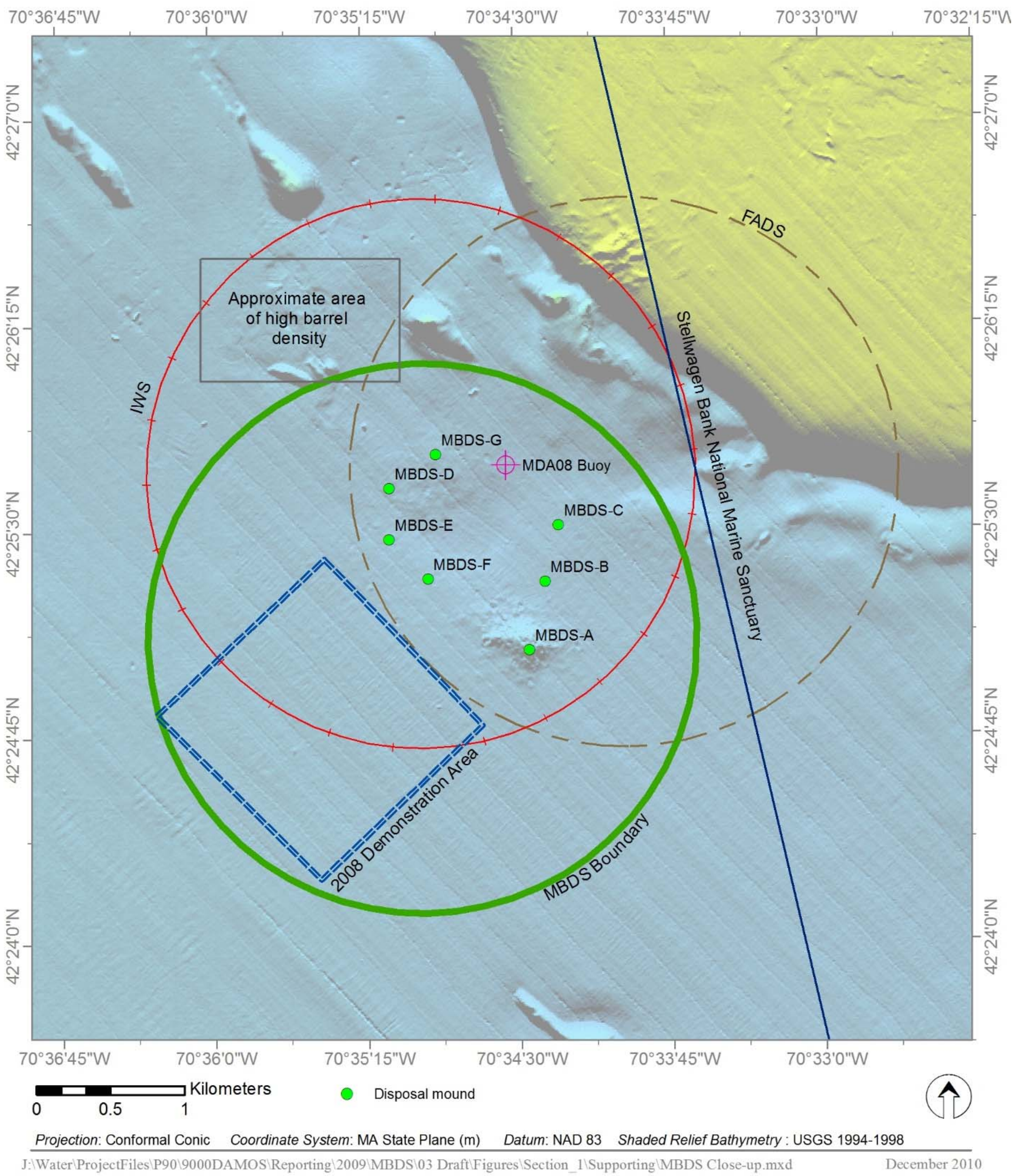

Figure 2-3: Boundaries of the IWS, FADS, MBDS, and the Stellwagen Bank National Marine Sanctuary

Table 2-1

Survey Chronology at IWS

Agency	Date	Survey Type	Reference
USACE	1973	Underwater video survey	Cited in Keith et al. 1999
USEPA, FDA, NOAA	1981-1982	Side-scan sonar Radiological analysis of sediment Radiological analysis of biota Radiological analysis of marketplace seafood samples	Lockwood et al. 1982, Curtis and Mardis 1984
USEPA, International Wildlife Coalition	1991	Side-scan sonar ROV inspection of waste containers	Wiley et al. 1991
USEPA, FDA, NOAA, DOE, MADPH	1992	Chemical and radiological analysis of sediment Chemical and radiological analysis of tissue Chemical and radiological analysis of marketplace seafood samples ROV and manned submersible inspection of waste containers ROV and manned submersible *in situ* radiological measurements	NOAA 1996 Keith et al. 1999
USEPA	2006 & 2010	Side-scan sonar	See Section 6.0

3.0 BACKGROUND ON CAPPING OF OPEN-WATER SITES

Capping has been used as a restoration practice in New England waters to minimize the environmental effects of contaminated sediment since as early as 1967 (Saila et al. 1969, Carey et al. 2012) when Providence Harbor, RI was specifically dredged in a sequential manner. Inner harbor sediments with elevated contaminant concentrations were placed on the seafloor in Rhode Island Sound first and later capped by sediments dredged from the outer portions of the harbor with relatively low contaminant concentrations. From that early experience, more specifically planned capping projects were designed and studied to better understand the cap building process and effectiveness (Cook et al. 1977; Morton 1980, 1983, 1987, 1989; Shonting and Morton 1981). Later studies demonstrated the success of these same caps over more than two decades since their construction (Fredette et al. 1992, Carey et al. 2006, 2012, SAIC 1995a, ENSR 2005) and these investigations have contributed to the broad acceptance of capping as a viable restoration alternative (USEPA 2005, 2013).

The physics of the water column processes and bottom spread of sediment following disposal has been extensively studied and can be reasonably predicted using numerical models (Gordon 1974, Johnson 1974, Holliday et al. 1978, Johnson et al. 1993, Johnson and Fong 1995). In more recent years, proposals to cap in-situ contaminated sediments have resulted in more detailed evaluations of the interaction of the descending sediment with the in-place bed sediments (Bratos et al. 2001, Fredette et al. 2002, McDowell et al. 2001, Valente et al. 2001, Walter and Fredette 2001) in order to understand the potential to remobilize those bottom sediments. The present study builds on the prior work which indicates that the impact and spreading process of the falling cap sediment is relatively limited in its lateral extent both in terms of the direct dislodgement of in-place sediment and the overall size of the deposit once the system comes to rest. However, for the purposes of planning an approach for covering the sediments at the IWS, it was necessary to better refine the details of the process and its effects on the sediments present in Massachusetts Bay.

3.1 Previous DAMOS Capping Investigations

Sediment capping was first introduced as a management technique in the DAMOS Program during the 1978–79 disposal season with the development of the Stamford-New Haven mounds (STNH-N and STNH-S) at the Central Long Island Sound Disposal Site (CLDS; SAIC 1995a). Additional capping projects in New England waters have included multiple capped sites within CLDS (Stamford-New Haven capping sites [STNH-N and STNH-S; SAIC 1980a, 1980b, 1980c, 1995a; ENSR 2005], Norwalk [SAIC 1980c, 1981, 1995a], Cap Site #1 and Cap Site #2 [SAIC 1995a; ENSR 2005], the Mill/Quinnipiac River [MQR; SAIC 1995a], and the New Haven Capping Project [SAIC 1996a]) and the New London Disposal Site (NL-TR Mound [SAIC 1990, 1995b, 1995c], Dow/Stonington [D/S] Mound [SAIC 2001a], U.S. Coast Guard Academy [USCGA] Mound [SAIC 2001a], NL-94 Mound [SAIC 2001a], and the Seawolf Mound [SAIC 2001b]); as well as previous capping demonstration projects at MBDS (SAIC 1994; Wiley 1995; SAIC 2003) and the Portland Disposal Site (SAIC 1996b, 1998). Monitoring results have consistently shown these caps to be stable with no evidence of contaminant release (SAIC 1995a).

3.2 Conceptual Model of Capping

When dredged sediment is released from a barge, it falls through the water column as a convective jet that impacts the bottom and then spreads laterally (Figure 3-1) until its kinetic energy is dissipated. During impact, the disposed sediment interacts with the bottom, dislodging and mixing with in-place sediment, and creating a scour zone or crater. As the laws of physics dictate, there is frictional energy loss as bottom sediments are placed into motion, generally radially outward from the point of impact, as well as energy loss due to the compaction of the underlying material. The radial movement introduces further friction with the bottom and continued mixing with stationary (relative to the radial spreading) ambient water. The bottom erosion and water mixing both continually dissipate the energy of the radial spread until the process comes to an end. During this event, some of the mixed sediment can deposit in the crater filling it back in to varying degrees, some of it may form a berm in a ring around the crater (a manifestation of a large drop in energy), and the remainder distributes as a thinning wedge of sediment in an apron around the central crater.

In water depths such as those present at the Massachusetts Bay Disposal Site the time from sediment release until bottom impact is only a few seconds, and bathymetric surveys have shown that the radial spread of material is a couple hundred meters in all directions. For the purposes of placing material at the IWS, the creation of the crater is clearly undesirable from the perspective of disturbing the in-place materials, but the less energetic lateral spread of sediment, which causes relatively low surface scour, is a process that can be used in planning an approach for restoring the site. Thus, the conceptual design for covering the IWS is as follows:

- Locate an area adjacent to the IWS where there is no evidence of barrels or containers and where disturbance of the in-place sediments is unlikely to cause any undesirable impact.

- Begin depositing sediment in this container/barrel-less area with multiple barge loads of dredged material allowing the lateral spread to build up layer by layer over the edge of the area to be covered until the apron becomes thick enough to protect the underlying in-place sediments from disturbance of direct placement (Figure 3-2). Thus, the lateral apron is intended to absorb the energy of the direct impact from subsequent disposals and protect the historic materials from disturbance.

- Gradually shift subsequent placements over this lateral apron area which will allow the leading, low energy spreading edge to move farther over the restoration area.

- Continue this process to build the cover material laterally with successive shifts of the disposal locations.

The restoration demonstration summarized in this report was developed to help inform actual design of this conceptual approach by attempting to determine:

1. Can material be placed with reasonable accuracy using standard operational techniques (for example, within 30 m of a disposal transect and within 100 m of a specific point on that transect)?

2. How deep and wide are impact craters?

3. Can a lateral apron be built up to effectively protect the underlying sediment?

4. Does this lateral apron effectively isolate the underlying sediment?

Answering the first question will help to determine the size of the area needed to begin the restoration operation and how far it should be from the area to be covered. Answering the second question will contribute to selecting the starting location, but will also help to determine how thick the protective apron should be built before the placement proceeds over the restoration area. Answering the third question will help to determine the volume needed to build the apron to design thickness before a lateral shift in placement begins. Answering the fourth question will contribute to determination of how thick the lateral apron needs to be to absorb the energy of the placement process.

Once answers to the questions are reasonably understood, the spacing of sediment placements and the thickness that must be achieved with the lateral apron can be more confidently defined. An additional consideration is that the demonstration was designed to evaluate the worst case scenario of instantaneous sediment release from the barges. However, it may be possible during final design, to identify opportunities to release the sediment in a way that results in less impact to the bottom by spreading the descending energy out over a larger footprint. This could involve more gradual release of the sediment by opening barge doors more slowly or releasing the sediments with the barge moving at a higher speed. This will provide an additional measure to minimize concerns of disturbing the in-place sediments.

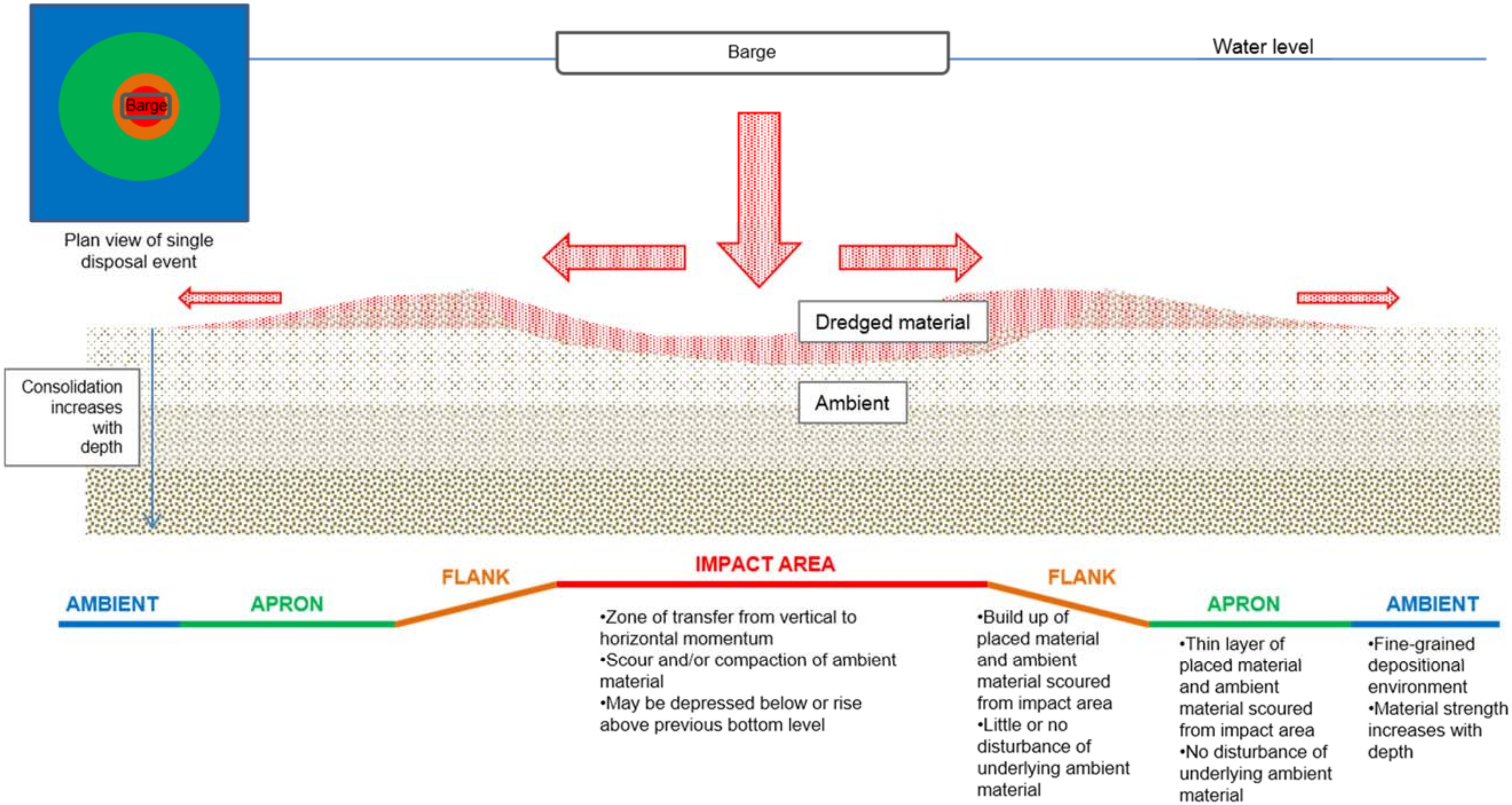

Figure 3-1: Conceptual site model of impacts to the seafloor from dredged material released from a split-hulled barge

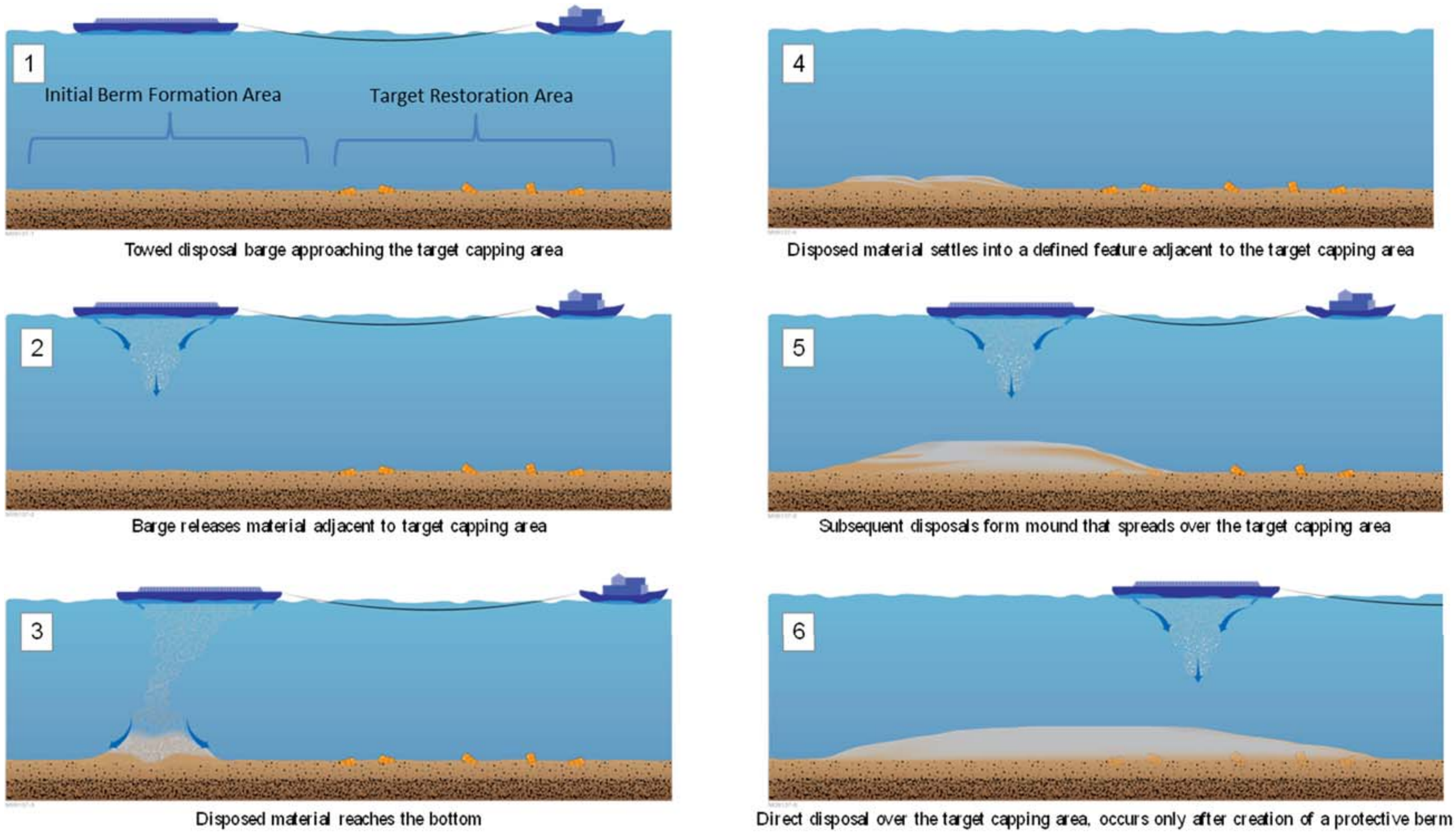

Figure 3-2: Restoration concept using sequential placements of dredged material from split-hulled barges

4.0 RESTORATION DEMONSTRATION METHODS

A team of investigators from AECOM, CR Environmental, and Germano and Associates performed the 2007, 2008, and 2009 surveys at MBDS. Field activities included multibeam bathymetry, SPI, and reconnaissance sediment coring as part of the 2007 monitoring survey of the overall MBDS; dedicated multibeam bathymetry, SPI, side-scan sonar, and a sub-bottom profiling in 2008; and a dedicated sediment coring survey in 2009. A summary of all survey events is presented in Table 4-1 and an overview of the methods used to collect, process, and analyze the survey data is provided below. A more detailed description of methodology and the related terminology can be found in ENSR (2004).

4.1 General Approach

To conduct the study, previous information from site investigations at MBDS was used to select an area within the disposal site that had a relatively flat bottom and minimal evidence of past dredged material disposal. This area, termed the Restoration Demonstration Area (RDA), is located to the southwest of the portion of MBDS that had been actively used in the years prior to the study (Figure 2-3). A baseline survey of this area was conducted in 2007 to refine the selection and establish the existing conditions (AECOM 2010). Results of the RDA baseline survey presented in the 2010 report included sediment profile images, sediment characteristics from four box cores, and bathymetry. Five additional baseline gravity/piston cores were collected as part of the demonstration project in 2009.

The first part of the demonstration study involved placing individual barge loads at discrete target locations to assess placement accuracy and the amount of bottom disturbance and lateral spread the individual sediment placements created. The next step, which was located in a separate portion of the study area, involved the creation of a sediment deposit using multiple placement events to create a lateral apron that would be about 0.5 meter thick. This was then followed by discrete placements on the apron area for comparison to the disturbance created from the placement of material on the ambient seafloor. The third step, involved creation of a berm with a thick lateral apron as a means to demonstrate the process at full-scale. A second berm deposit was created using relatively unconsolidated Boston Harbor maintenance sediments to the south of the first berm. The specifics of the placement operations were as follows:

<u>Line 0</u> - Released 11 separate barge loads, spaced 125 meters apart, along a target line within the RDA in order to (a) assess placement accuracy, (b) measure how deeply and widely the in-place sediment was affected by the falling sediment, and (c) measure the extent and thickness of the resulting apron (Figures 4-1, 4-2).

<u>Line 1</u> - On a second target line, isolated from the first, placed 11 individual disposal events spaced 125 m apart (Figures 4-1, 4-2). Placement of two to three additional barge loads was repeated at six of these target points to build up a somewhat thicker lateral apron

over a certain areas. The remaining single placement events elsewhere along this line contributed to the database of single disposal events, as above.

Line 1 Apron - Placed two individual barge loads of sediment on the partial lateral apron created on by Line 1 in order to assess the degree of protection the apron would provide to the underlying ambient sediment (Figures 4-1, 4-2). The apron thickness used in actual operations will likely be thicker than that used on Line 1, however, the Line 1 apron was intentionally constructed to be relatively thin in order to be able to detect the incremental benefit of a thin apron relative to when there was none on Line 0.

Lines 2–6 - At a third location within the study area, placed additional barge loads of sediment along a line followed by lateral shifts in placement to demonstrate the berm building process and to assess impact to in-place sediment (Figures 4-1, 4-2).

Line 7–9 - Lastly, at a fourth area, maintenance sediments that were being dredged from Boston Harbor were used to create a second berm (Figures 4-1, 4-2). This provided a contrast with the berm at Lines 2–6 that was created using the more cohesive sediment.

4.2 Specifics of Directing Placement

The material used for the demonstration project was generated during the construction of CAD cells in Boston Harbor. The 2008 Boston Harbor dredging project was a joint effort between the USACE and the Massachusetts Port Authority (Massport) that required the removal of approximately 1.5 million m^3 of material from several areas of the Harbor to improve navigation in the Main Ship Channel and to create two CAD cells (USACE and MassPort 2008). Approximately 750,000 m^3 of material had concentrations of metals, PCBs, PAHs, and pesticides that prevented open water disposal. The selected disposal alternative was to place this material into two newly created CAD cells (USACE and MassPort 2008).

The remaining 750,000 m^3 of material was deemed suitable for disposal at MBDS. A portion of the suitable material (380,000 m^3) was used for the demonstration project and consisted mostly of Boston Blue Clay, a highly consolidated glacio-marine deposit (Rosen et al. 1993), with smaller amounts of glacial till.

Dredged material suitable for open water disposal was transported by split-hull barge and tug to MBDS and deposited at the MDA08 buoy (Figure 2-3). Between June and October 2008 tug operators were directed to specific disposal locations within the RDA instead of the MDA08 buoy (Figure 4-2). An operations plan was developed for each phase of the demonstration that included coordinates for an approach point to the disposal line and the target itself (Figure 4-3). The coordinates were entered into the Automated Disposal Surveillance System (ADISS) that was used for all disposal operations, and a target box was created around the target disposal point (Figure 4-4). The box represented the area within which material could be placed. If the captain was unable to release the material within the target box, they were instructed to proceed to the standard placement location at the MDA08 buoy.

4.3 Survey Chronology

A baseline survey was performed in 2007 in order to select a suitable location for the demonstration project (AECOM 2010). Monitoring surveys were then scheduled throughout disposal operations in 2008 to document seafloor changes during the sequenced effort (Table 4-1 and 4-2). Data from the 2008 surveys were used to design a subsequent sediment coring effort in 2009.

The initial bathymetric and SPI monitoring surveys (20 June 2008) were conducted following the conclusion of disposal operations on Line 0 in order to assess conditions after placement of 11 individual barge loads on ambient sediment (Figure 4-5). SPI stations were selected to characterize impact points and the distribution of dredged material on the seafloor (Figure 4-6).

The second round of monitoring (11 July 2008) also included bathymetric and SPI surveys, with bathymetry focusing on Line 1 and the area south of Line 1 that would be used for disposal on Lines 2-6 (Figure 4-5). SPI stations were located at the southern extent of Line 1 allowing for a detailed investigation of the first several disposal impacts on that line (Figure 4-6). At the time of the July survey all 11 targets on Line 1 had received at least one disposal and targets 1-6 had received multiple disposals (Table 4-2).

The 29 August 2008 bathymetric survey covered disposal Lines 0, 1, and the Lines 2-6 complex area (Figure 4-5). SPI stations were located in several areas along Line 0 and Line 1 along with a tightly grouped set of SPI stations covering three disposal points just south of Line 1 (Figure 4-6). These three disposals were the first events of the demonstration project to be placed on the berm created by previous disposals.

The final bathymetric survey was conducted 16 October 2008 following the conclusion of all disposal operations for the demonstration project. This survey covered the entire RDA to allow for comparison of final conditions to baseline data (Figure 4-5).

A sub-bottom survey was also conducted in conjunction with the October bathymetric effort, but equipment limitations and sea conditions prevented the collection of usable data (see Section 4.7.1 Sub-Bottom Profile Data Collection). A subsequent sub-bottom survey was designed based on the results from the initial effort and was conducted over the majority of the RDA on 3 December 2008 (Figure 4-7).

A sediment coring program was designed following review of bathymetric, SPI, and sub-bottom data to characterize the impact of disposals and was conducted 13–16 July 2009. Core locations were selected to reflect the range of conditions encountered during the demonstration project including ambient material, disposals on ambient material, and disposals on a berm of disposed material (Figure 4-8).

Box cores were used at the ambient stations in an effort to preserve the surficial layer of the sediment-water interface with the goal of tracing the signature of that surface material in cores collected from impact points. Piston cores were collected at a subset of the ambient stations, and at all disposal stations, in order to achieve maximum penetration through the dredged material. Section 4.9 details the methodology for the sediment coring survey of the RDA.

4.4 Navigation and On-Board Data Acquisition

Positional data, comprised of horizontal positioning (x- and y-dimensional data) and time (t-dimensional data), were collected using a Trimble AG-132 Differential Global Position System (DGPS) unit. This system received and processed satellite and land-based beacon data and provided real-time vessel position, typically to sub-meter accuracy. HYPACK® hydrographic survey software, developed by HYPACK®, Inc., was used to acquire, integrate, and store all positional data from the DGPS as well as bathymetric and station data. The GPS receiver installed on the survey vessel was interfaced with the onboard navigation computer running HYPACK® software providing the field team with the ability to precisely navigate the vessel throughout the survey area and along the pre-selected survey tracklines for the bathymetric, sub-bottom, and side-scan sonar surveys and to the target stations for the SPI and sediment coring surveys.

4.5 Bathymetry

Bathymetric surveys provide measurements of water depth that, when processed, are used to map the seafloor topography. The processed data are compared to data from previous surveys to track changes in the size and location of seafloor features. This technique is the primary tool in the DAMOS Program for mapping the distribution of dredged material at disposal sites.

4.5.1 Bathymetric Data Collection

A baseline multibeam survey was conducted over the RDA as part of the monitoring cruise at MBDS in August 2007 (AECOM 2010). The 2008 multibeam bathymetric surveys were conducted on 20 June, 11 July, 29 August, and 16 October over a portion of MBDS and the RDA (Table 4-1, Figure 4-4). All surveys were conducted aboard the F/V Shanna Rose with sufficient line spacing and tie-lines to assure complete coverage of the survey areas.

The bathymetric data were collected using a Reson® 8101 Multibeam Echo Sounder (MBES) outfitted with a 1.5°, 240 kHz transducer. A gyro compass was used to provide accurate measurement of heave, pitch, and roll. The system was calibrated for local water mass speed of sound by performing conductivity-temperature-density (CTD) casts at frequent intervals throughout the day with a Seabird SBE-19 Seacat CTD profiler.

Water depths over the survey area were recorded in meters and referenced to mean lower low water (MLLW) based on local tidal data obtained from a project benchmark established at Boston Harbor Light using an In-Situ, Inc. Mini-Troll pressure transducer. Bathymetric data were recorded and stored within Hysweep®, a module of Hypack®, used to collect, display, and edit data from multibeam echosounder systems. Hysweep® also recorded acoustic backscatter, depth, vessel heave, heading, position, and time along each survey transect line.

4.5.2 Bathymetric Data Processing and Analysis

The bathymetric data were processed using the Hypack® software program and included corrections for tidal conditions, local speed of sound, and spurious data points. Tidal correction consisted of transforming the raw measurements of depth below the transducer to seafloor elevation measurements relative to MLLW using the locally collected tidal elevation data. Heave data supplied by the vessel's motion reference unit (MRU) were incorporated into the raw data to minimize the effects of vessel motion. The bathymetric data were also reviewed for spurious data points (clearly unrealistic measurements resulting from signal interference), and these points were removed. The final data set was averaged into 1.0 m^2 bins. All soundings located within a given bin were averaged, and the average value was assigned to the coordinates at the center of the bin.

Bathymetric data were analyzed to document the distribution of dredged material at RDA and evaluate changes in seafloor topography between the surveys. The corrected bathymetric data were analyzed using a combination of the contouring and surface plotting software program Surfer® 8.0, and the geographic information system software program ArcGIS® 9.3 (GIS). The processed bathymetric data were converted into grids using Surfer®, and bathymetric contour lines were generated and displayed using GIS.

Surfer® was also used to calculate depth-difference grids between the August 2007 baseline dataset and subsequent 2008 bathymetric data sets. The depth-difference grid was calculated by subtracting the 2007 survey depth estimates from the 2008 survey depth estimates at each point throughout the grid. The resulting depth differences were contoured and displayed using GIS.

4.6 Side-Scan Sonar

Side-scan sonar provides an image of seafloor texture and bottom type based on acoustic reflection and absorbance. These images can supplement bathymetric data to document the distribution of disposal material. For the demonstration project, these data were used to estimate the pattern and extent of impact features on the seafloor.

Side-scan sonar data were collected using three types of instruments; Reson® MBES, Edgetech® towfish, and Benthos® towfish. Side-scan and backscatter data, Reson® "snippets", were simultaneously recorded during each bathymetric survey (Table 4-1) using a 240-kHz Reson® 8101 MBES system. Towed side-scan sonar data were collected on 20

June and 11 July 2008 using a 100 kHz Edgetech® 260 system. On 3 December 2008, side-scan data were also collected using a towed 200 kHz Benthos® C3D interferometric swath system. The sections below detail acquisition and processing methods for each system.

4.6.1 Multibeam Backscatter and Side-Scan

4.6.1.1 Multibeam Backscatter and Side-Scan Data Collection

The Reson® 8101 MBES systems deployed during the bathymetric surveys were equipped with circuitry and software designed to allow acquisition of both side-scan and backscatter data which were recorded using Hysweep®. Side-scan data were sampled at a greater rate than bathymetric or backscatter data, and generated higher resolution seafloor imagery than the other two data sets. The 8101 system sampling rate for side-scan data was 5,000 Hz, resulting in approximately one sample per 15 cm of range. The spatial resolution of side-scan data was constrained by the system's 1.5° beam width, and has been estimated at approximately 0.8–2.0 m (depending on range).

A backscatter snippet is the series of amplitude values in the signal reflected from a beam's footprint on the seafloor. One snippet is produced for each of the system's 101 beams per sonar ping. These backscatter data can be combined with bathymetric data and normalized to allow semi-quantitative analysis of seabed texture. The spatial resolution of snippets data was equivalent to the resolution of bathymetric data, and was estimated at approximately 2–3 m^2 for survey depths at the RDA.

4.6.1.2 Multibeam Backscatter and Side-Scan Data Processing and Analysis

MBES side-scan data were processed using two software packages, SonarWeb® and GeoCoder®. Chesapeake Technologies, Inc. SonarWeb® software was used to generate georeferenced imagery for individual survey files (tracklines), preliminary mosaics, and HTML-navigable indices of some sonar data. Hypack®'s implementation of GeoCoder® software developed by NOAA's Center for Coastal and Ocean Mapping Joint Hydrographic Center (CCOM/JHC) was used to create mosaics best suited for substratum characterization through the use of innovative beam-angle correction algorithms.

Snippets backscatter data were extracted from survey files and were converted to Generic Sensor Format (GSF) files. Mosaics of beam time-series (BTS) backscatter data were created from GSF data using Hypack®'s implementation of GeoCoder® software, and were exported in grey-scale TIF raster format. BTS data for each survey event were also exported in ASCII format with fields for Easting, Northing, and backscatter (dB).

These data were gridded using Kriging algorithms. A mild low-pass Gaussian filter was applied to the grids to minimize nadir artifacts. The filtered grids were used to develop maps of backscatter values using five meter (horizontal resolution) node intervals. The grids were converted to ESRI® FLT raster format to facilitate comparison with other data layers using GIS and IVS3D Fledermaus®.

4.6.2 Towed Side-Scan Sonar

4.6.2.1 Towed Side-Scan Sonar Data Collection

Towed side-scan sonar data were acquired using an Edgetech® 260 system (current Edgetech® nomenclature: model 4100-P) on 20 June and 11 July 2008 (Table 2-1). The system consisted of an Edgetech® 272 TD towfish interfaced to a topside processor via an Analog Control Interface (ACI) circuit. The ACI allowed adjustment of both port and starboard signal gains as judged necessary by the sonar operator. Control of the ACI and sonar signal settings were accomplished using Chesapeake Technology, Inc. SonarWizMAP® acquisition software. The acquisition computer was interfaced to a Trimble® DGPS system via serial connection.

Sonar data were collected using a 100 kHz frequency and 150 m range scale to accommodate the range of water depths encountered over the survey area while expediting acquisition rates. Survey transects were spaced approximately 200 m apart to ensure greater than 100% insonification of the bottom (i.e., most portions of the seafloor were imaged at least twice). Based on the depth of towfish deployment (altitude above the seafloor), spatial resolution for this 1.2° beam-width system was estimated at approximately 1.0–3.0 m^2 (depending on range).

Towed side-scan sonar data were also collected on 3 December 2008 using a Benthos® C3D interferometric swath system. Data from this 200 kHz system were recorded using Hysweep®. Based on the depth of towfish deployment, spatial resolution for this 1.0° beam-width system was estimated at approximately 0.6–1.0 m^2 (depending on range).

4.6.2.2 Towed Side-Scan Sonar Data Processing and Analysis

Data for all three towed side-scan sonar surveys were processed using a combination of SonarWeb® and GeoCoder® software packages. After correction for towfish layback and signal attenuation, mosaics were created in georeferenced TIF and JPEG formats suitable for analysis using GIS.

4.7 Sub-Bottom Profiling

Sub-bottom profiling is used to characterize sediment features below the sediment-water interface based on acoustic impedance. These data were used in the demonstration project to estimate the depth and integrity of the original seafloor surface beneath newly placed material.

4.7.1 Sub-Bottom Profile Data Collection

Following the 16 October 2008 multibeam survey, a 10 kHz SYQwest® Stratabox sub-bottom profiling system was deployed over a limited portion of RDA to evaluate system capabilities. Data collected using this boom mounted system were of limited value due to rough seas and the transducer's large acoustic footprint (approximately 30 m^2 at 80 m depths).

On 3 December 2008 a towed sub-bottom profiling system was used to acquire stratigraphic data along a series of lines which intersected disposal regions of particular interest (Figure 4-7). The system consisted of a 2–7 kHz Benthos® CHIRP III single channel transducer array mounted within the same towfish body as the C3D swath system described above. The system was interfaced to an acquisition computer running Chesapeake Technology, Inc. SonarWizMAP® SBP software. The acquisition computer was interfaced to a Trimble® DGPS system via serial connection. Data were recorded in standard SEG-Y format. Lead weights installed in the towfish facilitated acquisition altitudes between 10–15 m above the seafloor. At this altitude (range), the acoustic footprint of the CHIRP II system was estimated at 5–8 m^2 at the seafloor.

4.7.2 Sub-Bottom Profile Data Processing and Analysis

Sub-bottom data were processed using Chesapeake Technology, Inc. SonarWeb® and SonarWizMAP® SBP software. Both software packages allowed correction for towfish layback. The precision of layback corrections was greatly enhanced by the simultaneously acquired C3D bathymetry/side-scan data, which allowed precise alignment between C3D and MBES data through fine-scale adjustments of layback values based on observed offsets between disposal feature positions observed in each data set. The horizontal accuracy of the processed data was estimated at 5–10 m.

SonarWeb® was used to apply time-varied gain (TVG) and to generate scaled profiles suitable for analysis in GIS. SonarWeb® also generated HTML-navigable indices of sonar profiles and navigation data. SonarWizMAP® SBP software was used to digitize surface and subsurface reflectors. Digitized points were exported in ASCII format and used to generate a GIS layer depicting the estimated thickness of disposal material in a portion of the survey area.

4.8 Sediment-Profile and Plan-View Imaging

Sediment-profile imaging (SPI) is a monitoring technique used to provide data on the physical characteristics of the seafloor as well as the status of the benthic biological community. The technique involves deploying an underwater camera system that photographs a cross section of the sediment-water interface. Acquisition of high-resolution sediment-profile images was accomplished using a Nikon D100 digital single-lens reflex camera mounted inside an Ocean Imaging Model 3731 pressure housing system. The pressure housing sat atop a wedge-shaped prism with a front faceplate and a back mirror. The mirror was mounted at a 45° angle to reflect the profile of the sediment-water interface. As the prism penetrated the seafloor, a trigger activated a time-delay circuit that fired an internal strobe to obtain a cross-sectional image of the upper 15–20 cm of the sediment column. The camera remained on the seafloor for approximately 20 seconds to ensure that a successful image had been obtained.

Test exposures of the Kodak® Color Separation Guide (Publication No. Q-13) were made on deck at the beginning and end of each survey to verify that all internal electronic systems were working to design specifications and to provide a color standard against which final images could be checked for proper color balance. After deployment of the camera at each station, the frame counter was checked to ensure that the requisite number of replicate images had been obtained. In addition, a prism-penetration depth indicator on the camera frame was checked to verify that the optical prism had penetrated the bottom to a sufficient depth. If images were missed, or the penetration depth was insufficient, the camera frame stop collars were adjusted and/or weights were added or removed, and additional replicate images were taken. Changes in prism weight amounts, the presence or absence of mud doors (to limit over-penetration in soft sediments), and frame stop collar positions were recorded for each replicate image.

Each image was assigned a unique time stamp in the digital file attributes by the camera's data logger and cross-checked with the time stamp in the navigational system's computer data file. In addition, the field crew kept redundant written sample logs. Images were downloaded periodically to verify successful sample acquisition and/or to assess the type of sediment/depositional layers present at a particular station. Digital image files were renamed with the appropriate station name immediately after downloading as a further quality assurance step.

Plan-view underwater images were also collected at each station sampled with the sediment-profile camera. An Ocean Imaging Model DSC6000 plan-view underwater camera (PUC) system with two Ocean Imaging Model 400-37 Deep Sea Scaling lasers was attached to the Model 3731 camera frame and used to collect plan-view photographs of the seafloor surface. The PUC system consisted of a Nikon D-70 camera encased in a titanium housing, a 24 VDC autonomous power pack, a 500 W strobe, and a bounce trigger. A weight was attached to the bounce trigger with a stainless steel cable so that the weight hung below the camera frame. The scaling lasers projected two red dots that were separated by a constant distance (27 cm) regardless of the field of view of the PUC, which could be varied by increasing or decreasing the length of the trigger wire.

As the camera apparatus was lowered to the seafloor, the weight attached to the bounce trigger contacted the seafloor prior to the camera frame hitting the bottom and triggered the PUC. Details of the camera settings for each digital image are available in the associated parameters file embedded in each electronic image file; for this survey, the ISO-equivalent was set at 800. Additional camera settings used were: shutter speed was 1/15, f10, white balance set to flash, color mode to Adobe RGB, sharpening to none, noise reduction off, and storage in compressed raw Nikon Electronic Format (NEF) files (approximately 5 MB each). Electronic files were converted to high-resolution JPEG (8-bit) format files (2000 x 3008 pixels) using Nikon Capture4® software (Version 4.4.2).

Prior to field operations, the internal clock in the digital PUC was synchronized with the GPS navigation system and the SPI camera. Each PUC image acquired was assigned a time stamp in the digital file, and redundant notations were made in the field and navigation logs. Throughout the survey, PUC images were downloaded at the same time as the sediment-profile images after collection and evaluated for successful image acquisition and image clarity.

4.8.1 SPI and PUC Data Collection

The 2008 SPI and PUC surveys were conducted in conjunction with the June, July, and August multibeam efforts aboard the F/V Shanna Rose (Table 4-1). At each station, the vessel was positioned at the target coordinates, and the camera was deployed within a defined station tolerance of 10 m. Three replicate images were collected at each station.

The June 2008 SPI survey design included 44 stations located on and to the north of disposal Line 0 within RDA (Table 4-3, Figure 4-6). The July 2008 SPI survey also consisted of 44 stations, focused around the southwestern end of disposal Line 1 (Table 4-3, Figure 4-6). The final SPI survey in 2008 was conducted in August and included 68 stations with 12 across the southernmost disposal event on Line 0, 27 in the southwestern portion of Line 1, 19 in the northeastern portion of Line 1, three in the disposal Lines 2–6 complex, and seven additional stations located between Lines 0 and 1 (Table 4-3, Figure 4-6).

4.8.2 SPI and PUC Data Analysis

Computer-aided analysis of the resulting images provided a set of standard measurements that can be compared between different locations and different surveys. The DAMOS Program has successfully used this technique for over 30 years to map the distribution of disposed dredged material and to monitor benthic recolonization at disposal sites.

Following completion of data collection, the digital images were analyzed using Bersoft Image Measurement© software version 3.06 (Bersoft, Inc.). Images were first adjusted in Adobe Photoshop® to expand the available pixels to their maximum light and dark threshold range. Linear and area measurements were recorded as number of pixels and converted to scientific units using the Kodak® Color Separation Guide for measurement calibration. Detailed records of all SPI results are included in Appendix B.

Analysis of SPI and PUC images was performed to provide the following information:

- Penetration depth
- Dredged material presence and depth
- Clay clump presence

- Bathymetric relief (high, moderate, low)
- Large scale roughness (from plan-view images)

4.9 Sediment Coring

In order to further describe sediments in the RDA, piston and box cores were collected for sediment characterization and analysis.

4.9.1 Sediment Collection

Sediment cores were collected within the RDA between 13 July and 16 July 2009 aboard the F/V Shanna Rose (Table 4-4, Figure 4-8). A total of 29 stations were targeted for core collection with an additional eight secondary stations to be sampled depending on time constraints. The locations were chosen to provide a cross-section of disposal scenarios and included ambient sediments, disposals on ambient material, and disposals on previous disposal material. For each station, the vessel was positioned at the target coordinates and the coring equipment was deployed within a defined station tolerance of 10 m.

For the ambient stations, a 0.0625-m^2 Gray O'Hara box corer was used to collect the sediment in order to minimize surficial sediment disturbance. Once the box core was retrieved, it was examined for acceptability, and residual water was removed using plastic tubing. The sample was visually examined for penetration depth, sediment color and texture, odor, and biota. Two to four 2 ⅝ inch (6.7 cm) diameter core tubes were outfitted with vacuum equipped caps and manually driven into the box core sample until refusal (Figure 4-9). Core compaction was documented by measuring the difference between the original sediment surface and the sediment surface inside the plastic core barrel. The tubes were then removed from the box core, capped, taped, and labeled.

A piston core was used at the remaining stations in order to penetrate through the disposal material into the underlying ambient sediment. The piston core was outfitted with a six foot (1.8 m), 3 ½ inch (8.9 cm) diameter core barrel, 300 pounds (136 kg) of weight, and set with a 25 foot (7.6 m) trigger cable (Figure 4-10). A co-located piston core was also collected at three of the ambient stations to provide for comparisons at depths greater than box core penetration.

All samples were stored vertically in a walk-in cooler at the Allerton Yacht Club in Hull, MA for the duration of the survey and then transported by truck, under chain of custody, to the University of Rhode Island Marine Geological Samples Laboratory (URI MGSL) for processing and analysis.

4.9.2 Core Processing

Cores were split vertically in half using a splitting device consisting of two opposing router bits designed to travel the length of the core tube in parallel until the plastic was severed. After the plastic core tube was severed, a wire was pulled through the sediment to complete the splitting process. Next, the two sediment halves were separated and sealed with plastic film for short term storage.

After splitting the core, one core half was transferred to the subsampling team and the second half was transferred to the GeoTek™ logging laboratory for high resolution imaging and non-destructive analysis of bulk density, magnetic susceptibility, resistivity, and p-wave velocity.

Descriptions of each core were prepared, unique features were photographed, shear vane measurements were taken along the core profile, and subsamples were collected for moisture, bulk density, grain size, Atterberg Limits, specific gravity, carbon-hydrogen-nitrogen (CHN), and ^{210}Pb analysis (Table 4-5, Figure 4-11).

4.9.3 Core Logging

The sediment core halves designated for GeoTek™ logging were prepared for digital scanning by scraping the exposed sediment along the horizontal to provide a fresh, unaltered sediment surface. Next, the cores were scanned with a 100 dpi down-core resolution and a 143 dpi or 183 dpi cross-core resolution for the box cores and piston cores, respectively. The majority of the cores were then measured to characterize the physical properties at 2 cm intervals, but a subset of eight cores (1-4, 1-5, 2-5, 3-2, 4-1, 5-1, 5-2, and 5-3) were measured at 1 cm intervals.

Sediment wet bulk density measurements were estimated by passing gamma particles (^{137}Cs source) through the sediment and counting the number of particles that passed through an opposing (Na-I) counter. The attenuation, or “scattering”, of particles was proportional to the density of the material. The sensor was first calibrated using different thicknesses of water and aluminum because these substances encompass the typical range of sediment densities and have similar scattering properties.

Magnetic susceptibility refers to the magnetization of the sediment in the presence of a weak magnetic field and was used as an indicator of the amount of magnetic material (Fe) present in the sediment. Magnetic susceptibility profiles were established using a Barrington Instruments® MS2E point sensor.

Resistivity profiles were developed using a non-contact resistivity sensor by generating a weak magnetic field that induced a current in the sediment porewater. Sensor calibration was performed using water of various salinities. In fresh sediment, resistivity may be used to characterize the amount and type of porewater, or in the case of dewatered sediments (often the case with split cores), resistivity more accurately characterizes porosity because the dewatering leaves void spaces filled with highly resistive air.

Compressional wave or P-wave velocity through sediment is related to the sediment bulk density and porosity. Velocity profiles were measured using a pad-type transducer (positioned on the sediment surface) and an oil-filled, roller-bearing transducer on the opposing/underside of the core. Unfortunately, dewatered sediments or gas bubbles can interrupt P-wave travel time within selected core sections. These data were of lesser value for the purposes of this project and are not discussed further.

4.9.4 Core Analysis

Shear data were collected using a Torvane Penetrometer. Samples were dried overnight in a 105°C oven to collect moisture data. Atterberg Limits and specific gravity were measured according to ASTM protocol (4318 and 854, respectively). CHN data were collected using a CHN analyzer (Exeter Analytical, CE-440 Elemental Analyzer), and ^{210}Pb data were recorded using a gamma spectrometer (Canberra, GL2020S [planar] and GCW-3023 [well]) at the University of Rhode Island Graduate School of Oceanography.

Radiochemical samples were received dried in plastic vials. For samples analyzed using the well detector, approximately 3–5 g of sediment was placed into plastic sample tubes, capped with epoxy, and stored for 2–3 weeks for ^{222}Rn to equilibrate with ^{226}Ra. For samples analyzed using the planar detector, approximately 10 g of sediment were analyzed. Samples were gamma counted using either a pure Ge well detector (Canberra GCW-3023, 150 cm^3 active volume) or pure Ge planar detector (Canberra GL2020S) for ^{210}Pb, ^{226}Ra, and ^{137}Cs. The gamma energies measured were 46.5 KeV for ^{210}Pb, 352 KeV (^{214}Pb) for ^{226}Ra, and 661 KeV for ^{137}Cs. It was not possible to directly determine ^{226}Ra using the planar detector. Counting efficiencies for ^{210}Pb, ^{226}Ra (^{214}Pb) and ^{137}Cs were obtained by counting sediment standards obtained from NIST.

Sediment samples were analyzed for CHN using an EA-440 Elemental Analyzer (Exeter Analytical). Samples were dried, ground, and then packaged into ultra-clean tin capsules and nickel sleeves for analysis.

A limited number of cores were also selected for consolidation testing. Co-located cores from three ambient locations (Stations 2, 3, and 5) were selected for one-dimensional consolidation testing (ASTM D 2435) and consolidated un-drained triaxial compression testing (ASTM D4767). Four demonstration area cores (Stations 8, 32, 33, and 36) were also selected for the one-dimensional consolidation testing.

4.10 Development of a Crater Modeling Tool

Following data collection activities, an analytical screening tool was developed to evaluate the potential impact of other material placement scenarios on native sediments at the IWS. The analytical tool was based on impact coefficients developed through published laboratory experiments that were modified to fit site specific conditions at the IWS based on empirical data from this demonstration project. The tool could be used to further refine an effective restoration approach by expanding on the suitable range of placement volumes and source material characteristics that could be used to achieve the project goals. A brief discussion of the approach is outlined below; a complete explanation of the theory, assumptions, and application of the model are presented in Appendix M; results are presented in Section 5.7.

The model analyzed two different sets of impact scenarios; craters formed from the impact of a single cohesive particle like a consolidated block of Boston Blue Clay, and craters formed from the impact of a cloud of sediment released from a barge. For the single particle exercise spherical and cubic chunks with dimensions or edge lengths of 0.25, 0.5, 1.0, and 2.0 meters were considered as sizes potentially generated through mechanical dredging operations of the Boston Harbor project. The analytical tool modeled the effect of size, shape, and composition (BBC or granite) on particle mass and velocity during placement in order to calculate the kinetic energy of the particle which in turn dictates the dimensions of the resulting crater (see Appendix M for a complete description of the model inputs and assumptions).

In application, the actual restoration of the IWS would involve the release of barge loads of material that would descend through the water column as a cloud of sediment and not as a single cohesive chunk. The particle model was then adapted to analyze the impact forces of a descending cloud of material. By calculating the mass and velocity of the cloud at impact, the change in momentum could be determined and adjusted for horizontal spreading, which could then be used to determine the peak force and resulting crater formation.

Since water is entrained in the sediment cloud as it descends through the water column the bulk density of the cloud could not be determined through the simplified approach of calculating the volume of the cloud at the release point and inputting the mass of the sediment. In addition, drag also acts on the surface of the sediment cloud, altering its shape and volume as it descends. A numerical model that could step through the cloud descent in small increments to apply the drag force, water entrainment, and other terms was needed to estimate the impact velocity and volume. The USACE model STFATE was used to capture the effects of these factors on the cloud during placement in order to calculate the kinetic energy at impact and better predict the resulting crater (see Appendix M for a complete description of the STFATE inputs, assumptions, and scenarios).

Figure 4-1: Overview of different investigation areas within the RDA

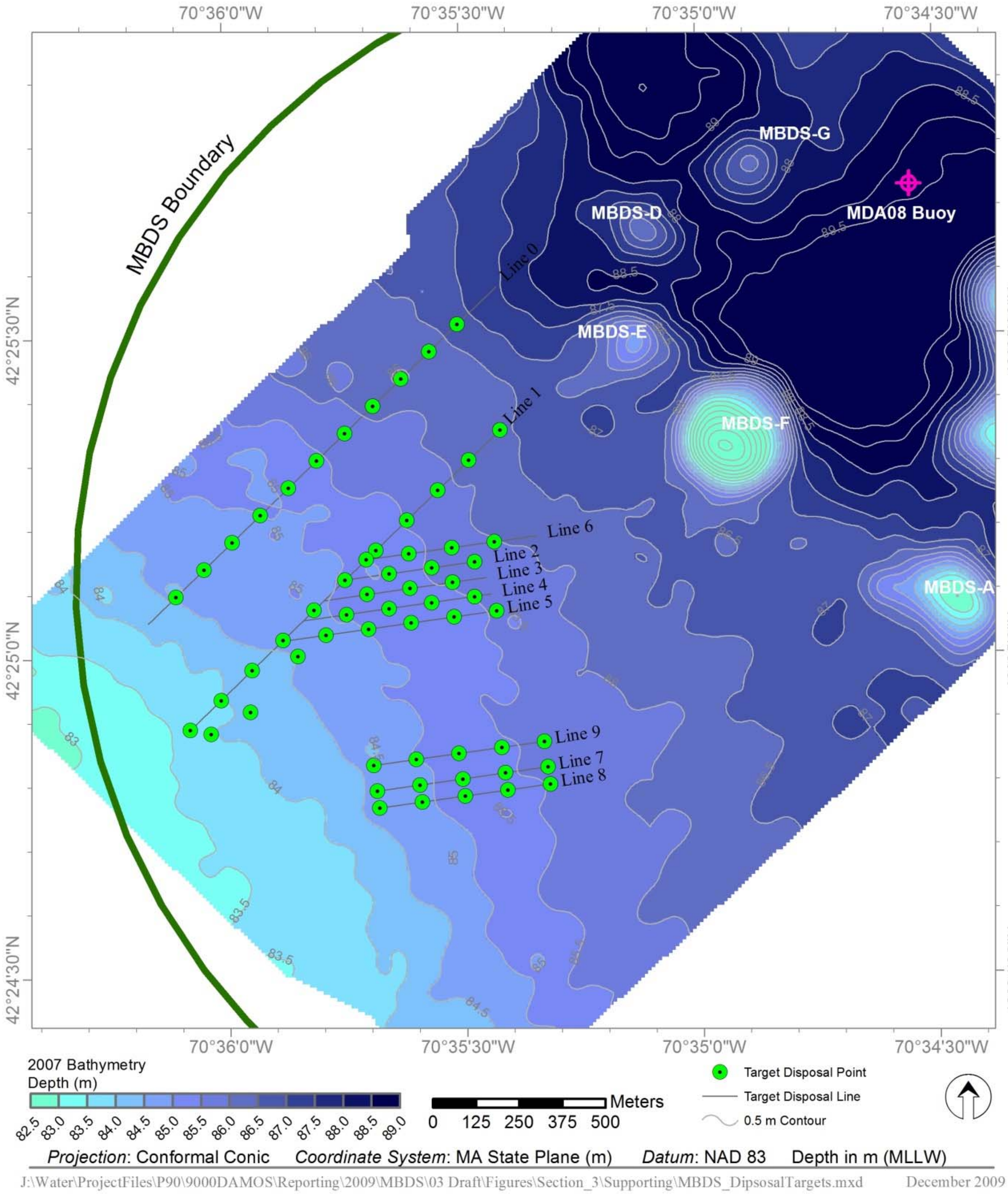

Figure 4-2: Target placement locations along preset lines within the RDA

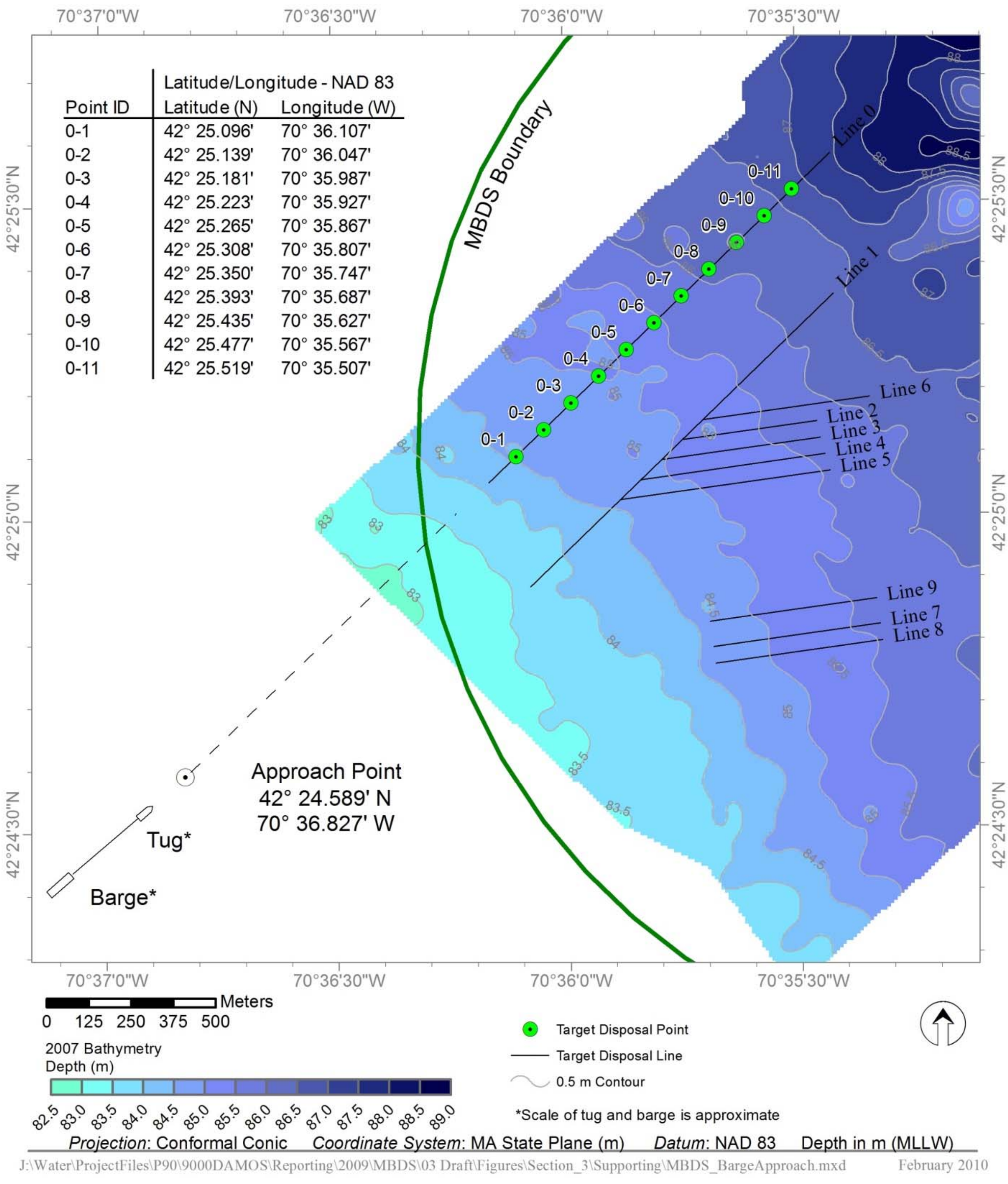

Figure 4-3: Example of placement directive along Line 0

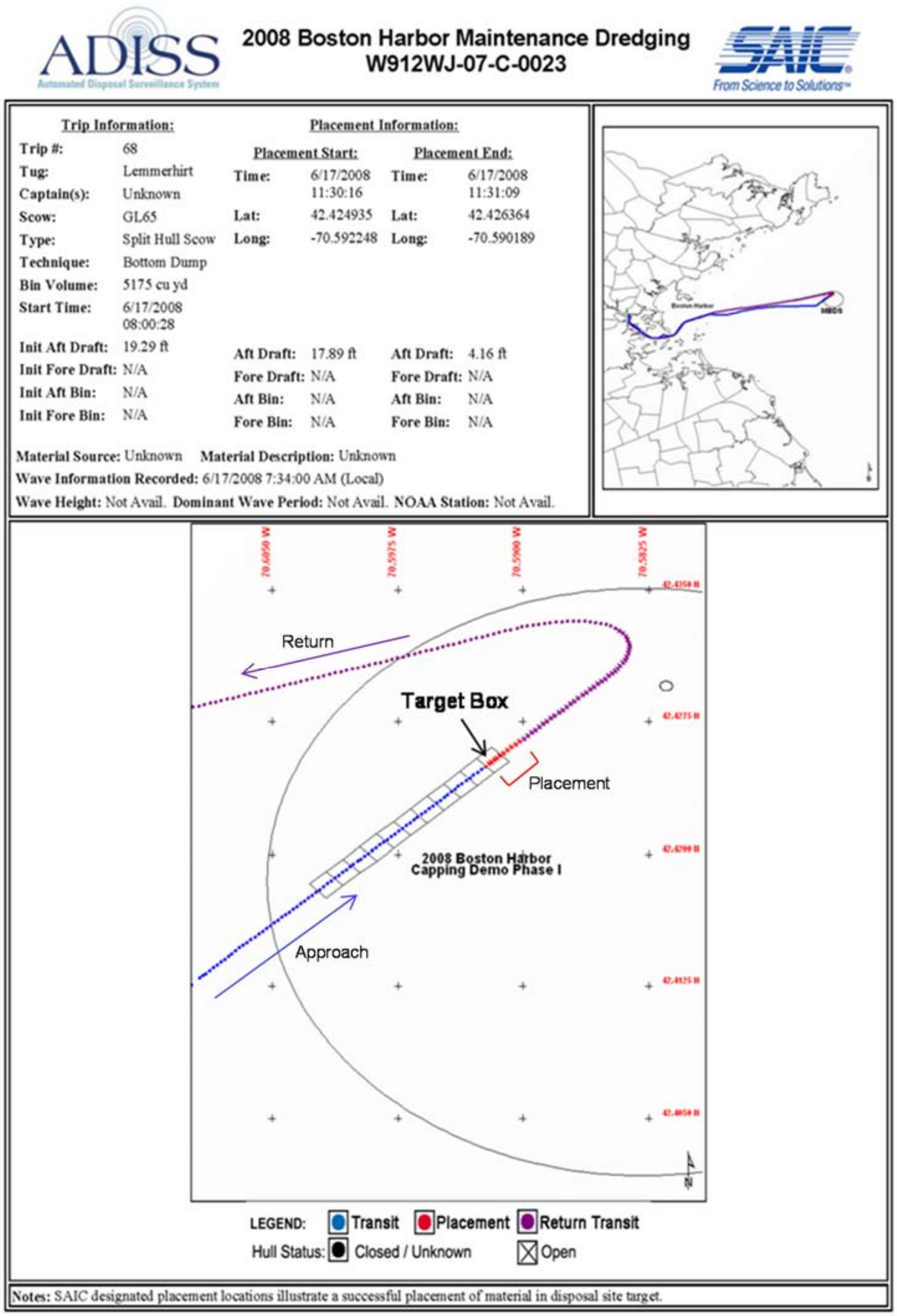

Figure 4-4: Example output of electronic disposal barge position tracking (from SAIC ADISS)

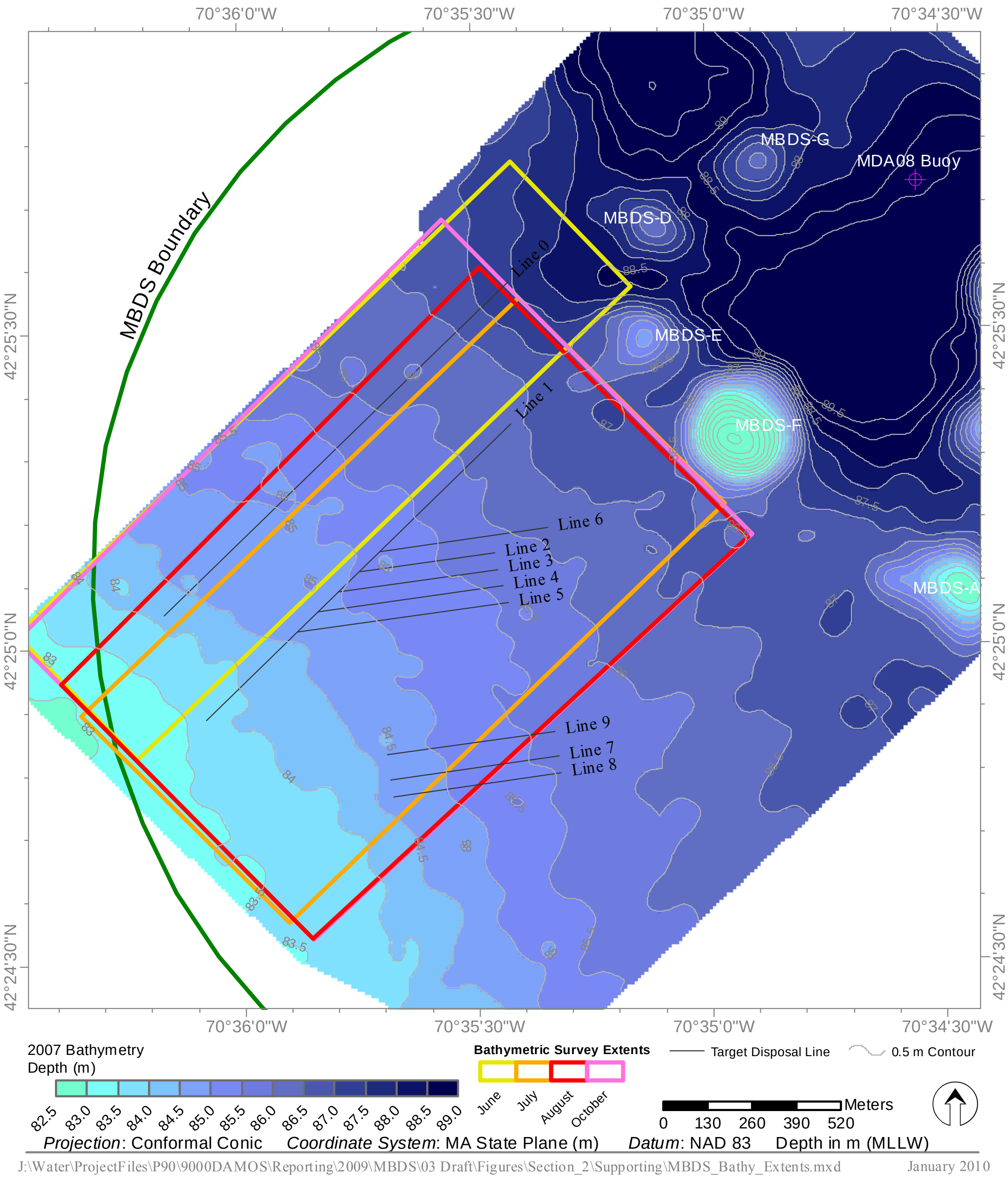

Figure 4-5: Coverage areas for 2008 bathymetric surveys of the RDA

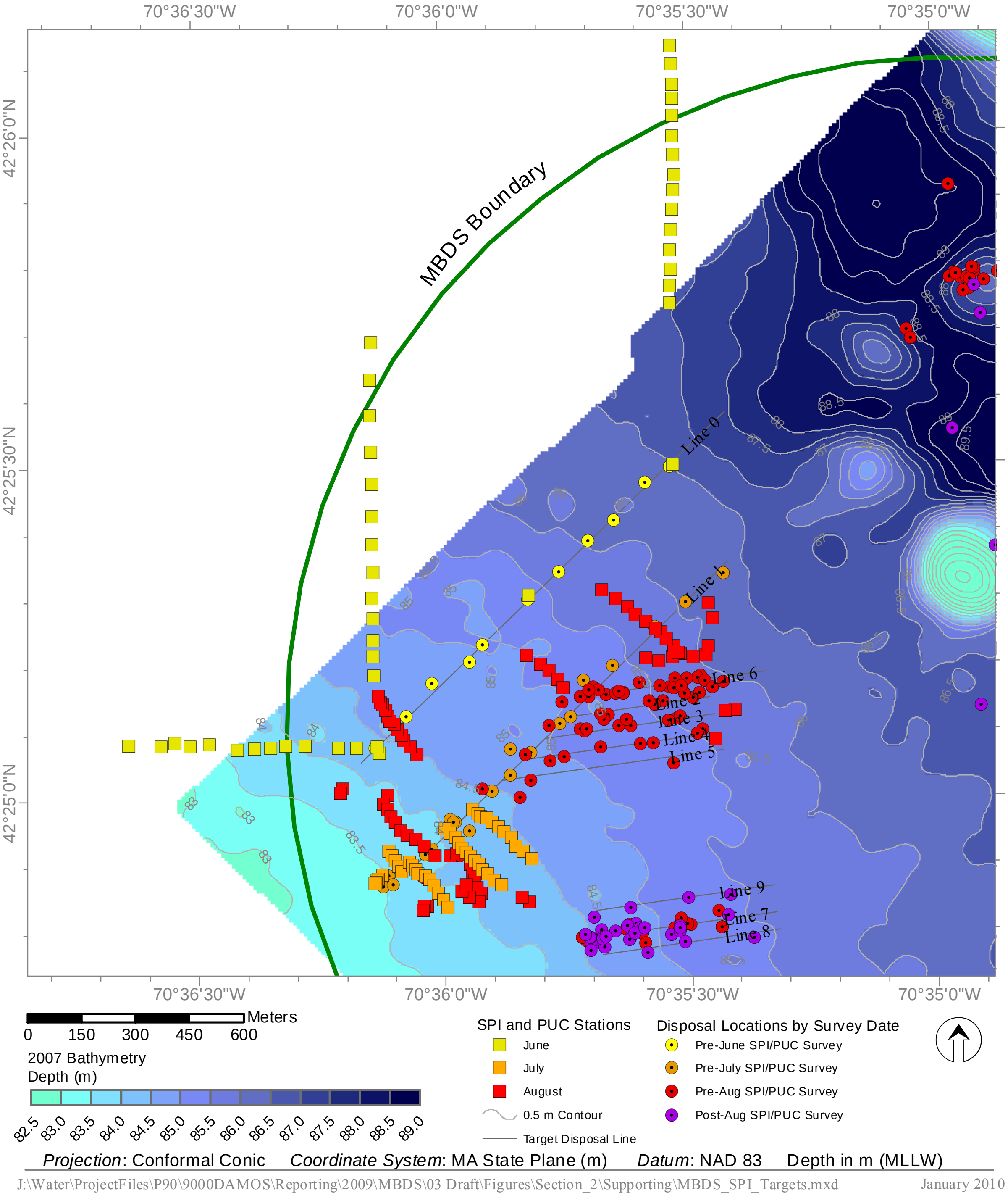

Figure 4-6: SPI/PUC stations for the 2008 surveys showing corresponding material placement locations

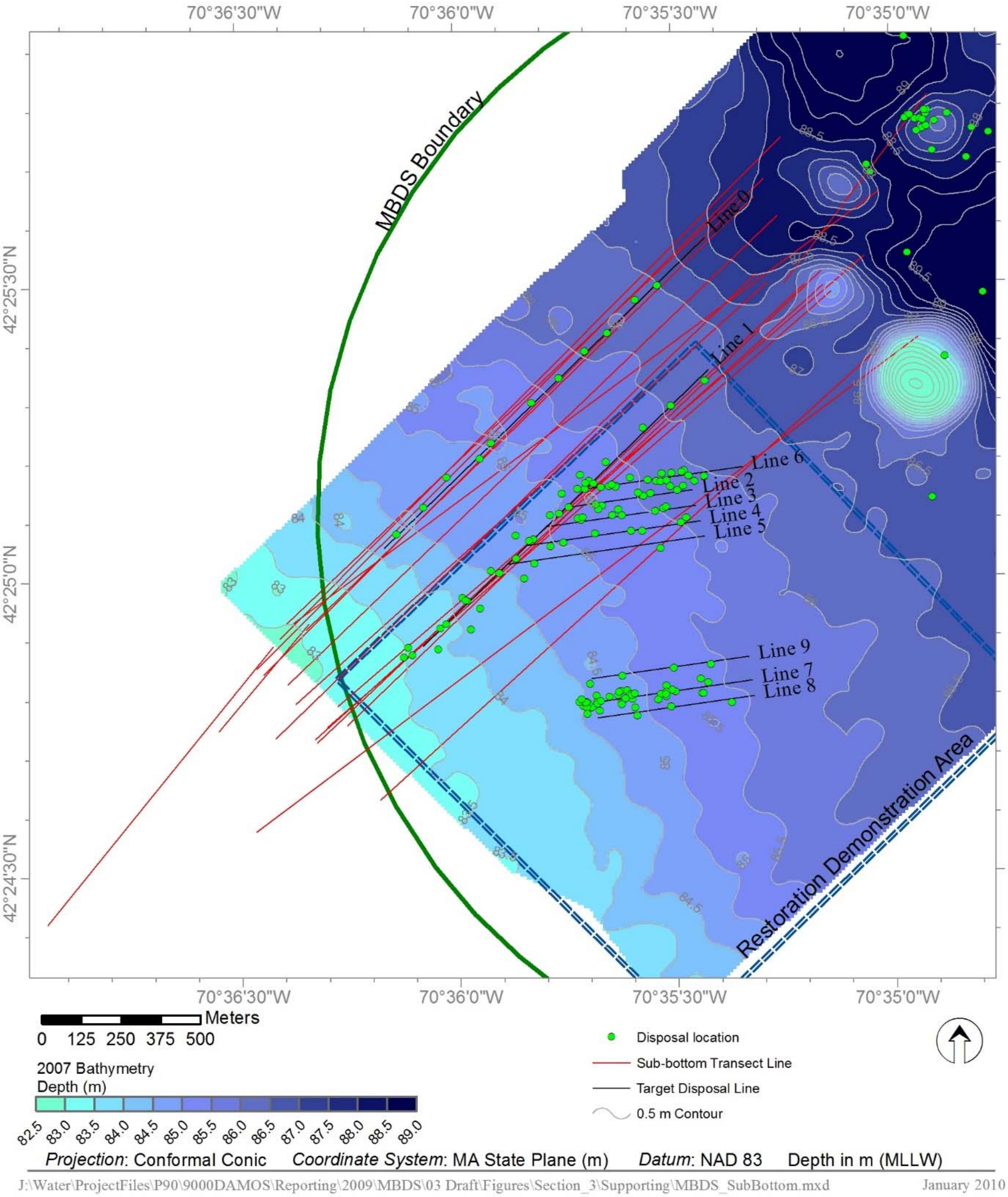

Figure 4-7: Sub-bottom transect lines for the December 2008 survey

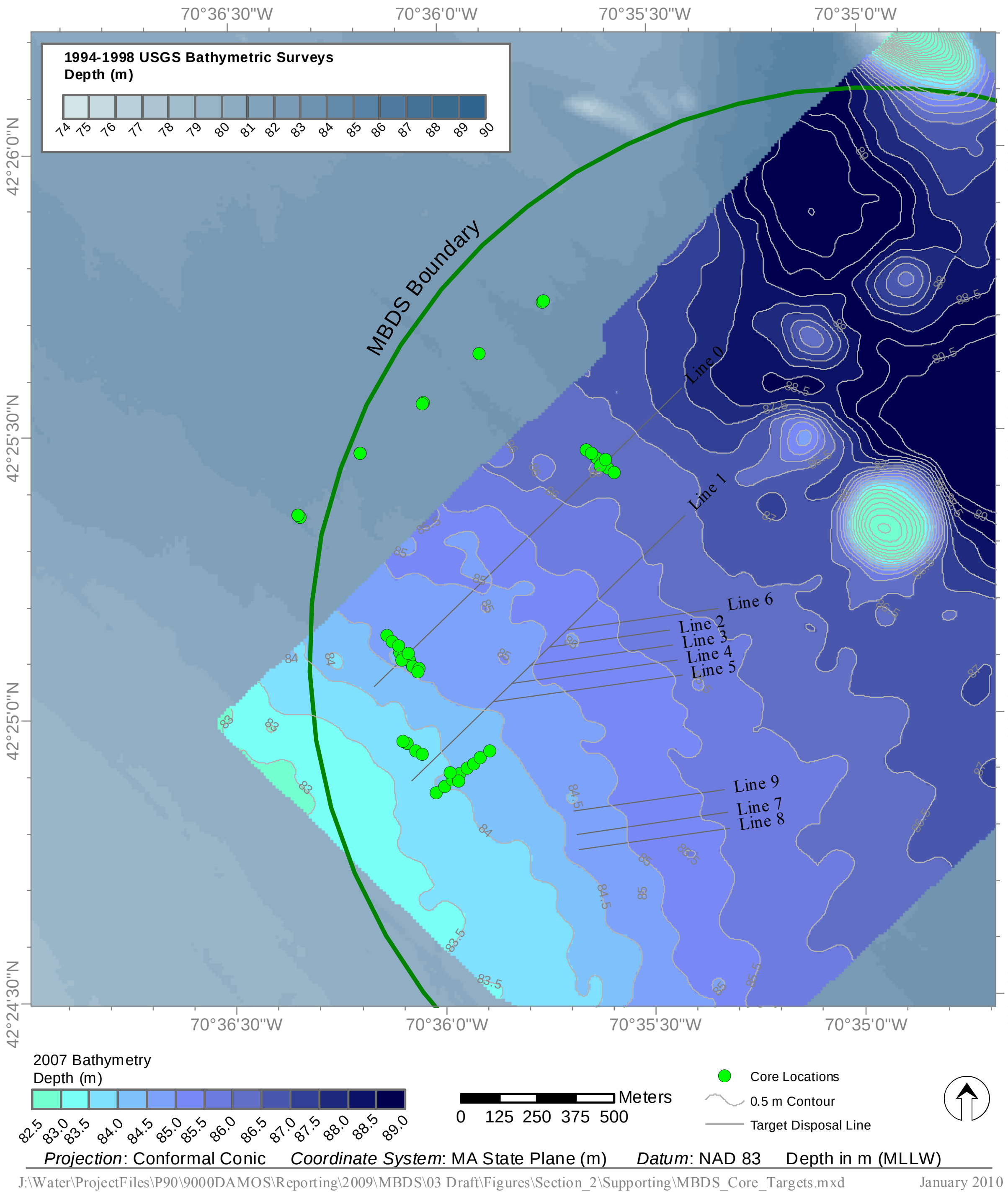

Figure 4-8: Locations of sediment cores collected in July 2009

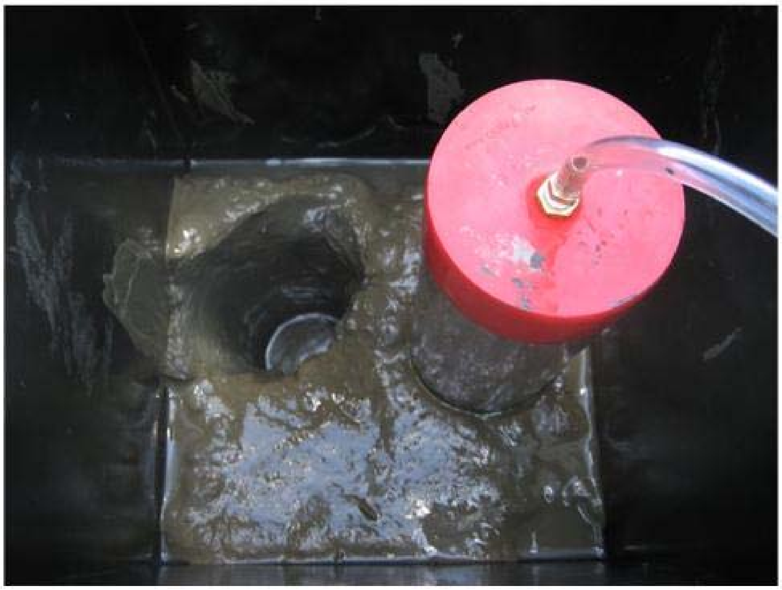

Figure 4-9: Box core with manually collected sub-core to capture minimally disturbed sediment water interface at the ambient stations

Figure 4-10: Piston core used to penetrate through the placed dredged material into the underlying ambient sediment

Demonstration Area Core

Interval No.	Interval Depth (cm)	Piston Core		Comment
CDM not sampled				
1	NA	GS, D, A, C	-	Bottom of CDM
2	0-3	GS, D, A, C	Pb^A	
3	3-6	GS, D, C		
4	6-9	GS, D, A, C	Pb^A	
5	9-12	GS, D, C		
6	12-18	GS, D, C	Pb^A	
7	18-24	GS, D, A, C	Pb^A	
8	24-30	Archive	Pb^A	
9	30-36	Archive	Pb^A	Estimated BAZ limit (26-35 cm)

Ambient Core

Interval No.	Interval Depth (cm)	Box Core I	Box Core II	Piston Core		Comment
1	0-3	GS, SG, D, C	Backup	Pb		
2	3-6	GS, SG, D, A, C	Backup			
3	6-9	GS, SG, D, C	Backup	Pb		
4	9-12	GS, SG, D, A, C	Consolidation/CU/CU Triaxial			
5	12-15	GS, D, C	Backup	Pb		
6	15-18	GS, D, A, C	Triaxial			
7	18-21	GS, D, C	Backup	Pb		
8	21-24	GS, D, A, C	Backup			
9	24-27	GS, D, C	Backup	Pb		
10	27-30	GS, D, A, C	Backup			Estimated BAZ limit (26-35 cm)
11	30-36	GS, D, C	Backup	Pb	Replicate	Box core limit (36 cm)
12	36-42			Pb	GS, D, A, C	
13	42-48			Pb^A	GS, D, C	
14	48-54			Pb^A	GS, D, A, C	
15	54-60			Pb^A	Archive	
16	60-66			Pb^A	Archive	
17	66-72			Pb^A	Archive	
18	72-78			Pb^A	Archive	
↓						
26	120-126			Pb^A	Archive	EOC

Key

A	Atterberg Limits	Capping dredged material (CDM)
BAZ	Biologically Active Zone	Surface Ambient
C	CHN	Deep Ambient
D	Density/Moisture	
EOC	End of Core	
GS	Grainsize	
Pb	^{210}Pb	
Pb^A	Archive for ^{210}Pb	
SG	Specific Gravity	

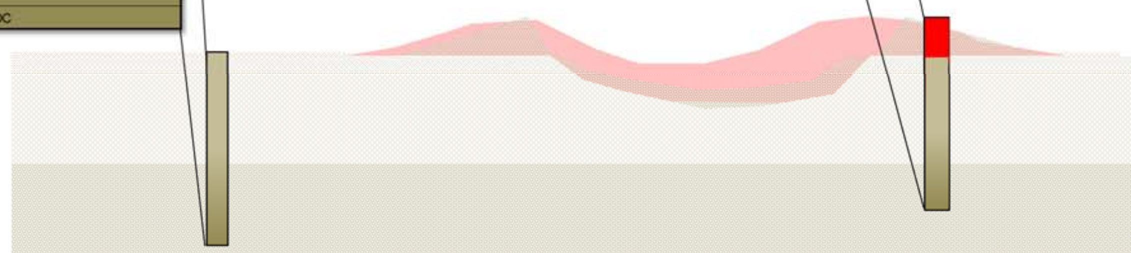

Figure 4-11: Sediment core sampling scheme

Table 4-1

Demonstration Survey Events at MBDS

Survey	Date	Survey Type	Summary
2007 Baseline (AECOM 2010)	7 August 2007	Multibeam, SPI, grab	Area: 2100 x 3200 m SPI stations: 63 (18 in RDA) Sediment sampling stations: 4
Line 0	20–22 June 2008	Multibeam, side-scan sonar, SPI	Area: 500 x 2000 m SPI stations: 44
Line 1	11–15 July 2008	Multibeam, side-scan sonar, SPI	Area: 850 x 1800 m SPI stations: 44
Lines 2-6	29–31 August 2008	Multibeam, SPI	Area: 1100 x 1800 m SPI stations: 68
Post Line 1	16 October 2008	Multibeam, sub-bottom	Area: 1500 x 1800 m
Post Line 2	3 December 2008	Sub-bottom, side-scan	Lines: 19
Coring	13–16 July 2009	Cores	Sampling stations: 37

Table 4-2

Disposal and Survey Chronology of the Demonstration Project

Disposal Event			Target Location			GLDD Estimated Volume (m^3)
GLDD Trip #	**Date**	**Time**	**Line**	**Point**	**Disposal #***	
58	11 June 2008	1943	0	0-1	1	4281
59	12 June 2008	0656	0	0-2	1	4109
60	12 June 2008	1901	0	0-3	1	4205
61	13 June 2008	0822	0	0-4	1	4205
62	13 June 2008	2333	0	0-5	1	4358
63	14 June 2008	1214	0	0-6	1	4205
64	15 June 2008	0014	0	0-7	1	4205
65	15 June 2008	1533	0	0-8	1	4358
66	16 June 2008	0440	0	0-9	1	4281
67	16 June 2008	1822	0	0-10	1	3823
68	17 June 2008	1130	0	0-11	1	3957
69-72	17-19 June 2008			buoy		
73	20 June 2008	0221	1	1-1	1	4281
Multibeam bathymetric survey conducted 20 June 2008 on Line 0						
74	20 June 2008	1326	1	1-3	1	
75	21 June 2008	0529	1	1-3	2	
76	21 June 2008	1654	1	1-4	1	
SPI survey conducted 22 June 2008 on Line 0						

Table 4-2, continued

GLDD Trip #	Disposal Event Date	Time	Target Location Line	Point	Disposal #*	GLDD Estimated Volume (m^3)
77	22 June 2008	1130	1	1-5	1	4281
78	23 June 2008	0038	1	1-6	1	4358
79	23 June 2008	1427	1	1-7	1	4396
80	24 June 2008	0324	1	1-8	1	4358
81	24 June 2008	1624	1	1-9	1	3823
82	25 June 2008	0651	1	1-10	1	4205
83	25 June 2008	1812	1	1-11	1	4358
84	26 June 2008	1450	1	1-1	2	4129
85	26 Jun 2008	2208	1	1-2	1	4281
86	27 June 2008	0758	1	1-3	3	4281
87	7 July 2008	2122	1	1-4	2	4411
88	8 July 2008	0808	1	1-5	2	4480
89	8 July 2008	1512	1	1-6	2	4266
90	8 July 2008	2135	1	1-1	3	4274
91	9 July 2008	0400	1	1-2	2	4488
92	9 July 2008	1047	1	1-3	4	3517
93-101				buoy		
Multibeam bathymetric survey conducted 11 July 2008 on Line 1						
102	14 July 2008	1118	1	1-4	3	4434
103	14 July 2008	1813	1	1-5	3	4281
104	15 July 2008	0408	1	1-6	3	4281
SPI survey conducted 15 July 2008 on Line 1						

Table 4-2, continued

GLDD Trip #	Disposal Event Date	Time	Target Location Line	Point	Disposal #*	GLDD Estimated Volume (m^3)
105	15 July 2008	1036	2	2-2	1	4281
106	15 July 2008	1829	2	2-3	1	4320
107	16 July 2008	0131	2	2-4	1	4281
108	16 July 2008	0808	2	2-2	2	4281
109				buoy		
110	17 July 2008	0725	2	2-3	2	3804
111	17 July 2008	2153	2	2-4	2	4358
112	18 July 2008	1104	2	2-2	3	4339
113	18 July 2008	2240	2	2-3	3	4434
114	19 July 2008	0536	2	2-4	3	4434
115	19 July 2008	1525	3	3-2	1	4281
116	19 July 2008	2230	3	3-3	1	4358
117	20 July 2008	0656	3	3-4	1	4434
118	20 July 2008	1453	3	3-2	2	4626
119	21 July 2008	0241	3	3-3	2	4358
120	21 July 2008	1555	3	3-4	2	4434
121	22 July 2008	0041	3	3-2	3	4434
122	22 July 2008	0905	3	3-3	3	4358
123	22 July 2008	1953	3	3-4	3	4511
124	23 July 2008	0336	4	4-2	1	4281
125	31 July 2008	2254	4	4-3	1	4052
126	1 August	0715	4	4-4	1	4358
127	1 August	1513	4	4-5	1	4281
128	2 August	0016	4	4-2	2	4511
129	2 August	0636	4	4-3	2	4281
130	2 August	1322	4	4-4	2	4281
131	2 August	2238		buoy		4281
132	3 August	0512	single	A	1	4281
133	3 August	1213	4	4-5	2	4281
134	3 August	1912	single	B	1	4281

Table 4-2, continued

GLDD Trip #	Disposal Event: Date	Disposal Event: Time	Target Location: Line	Target Location: Point	Target Location: Disposal #*	GLDD Estimated Volume (m^3)
135	4 August 2008	0204	single	C	1	4281
136	4 August 2008	0817	5	5-2	1	4281
137	4 August 2008			buoy		
138	4 August 2008	2332	5	5-5	1	4281
139	5 August 2008	1128	5	5-6	1	UNK
140-151	5-9 Aug 2008			buoy		
152	9 August 2008	2155	6	6-1	1	4587
153	10 August 2008	0502		buoy		4281
154	10 August 2008	1351	6	6-2	1	4358
155	10 August 2008	2212	6	6-3	1	4434
156	11 August 2008	0515	6	6-4	1	4281
157	11 August 2008	1254	6	6-1	2	4358
158	11 August 2008	2229	6	6-2	2	4434
159	12 August 2008	0813	6	6-3	2	4434
160	12 August 2008	1657	6	6-4	2	4511
161	12 August 2008	2357	6	6-1	3	4511
162	13 August 2008	0741	6	6-2	3	4511
163	13 August 2008	1510	6	6-3	3	4511
164	13 August 2008	2126	6	6-4	3	4511
165	14 August 2008	0510	6	6-1	4	4511
166	14 August 2008	2110	6	6-2	4	4511
167	15 August 2008	0532	6	6-3	4	4511
168	15 August 2008	1523	6	6-4	4	4511
169	15 August 2008	2202	6	6-1	5	4511
170	16 August 2008	0619	6	6-2	5	4434
171	16 August 2008	1249	6	6-3	5	4511
172	17 August 2008	0007	6	6-4	5	4511

Table 4-2, continued

	Disposal Event		Target Location			GLDD
GLDD Trip #	Date	Time	Line	Point	Disposal #*	Estimated Volume (m^3)
173	17 August 2008	0702	6	6-1	6	4511
174	17 August 2008	1323	6	6-2	6	4511
175	18 August 2008	0252	6	6-3	6	4587
			Lines 7-9 and buoy			23 Disposals
Multibeam bathymetric survey conducted 29 August 2008 on Lines 2–6						
			Lines 7-9 and buoy			6 Disposals
SPI survey conducted 31 August 2008 on Lines 2–6						
			Lines 7-9 and buoy			40 Disposals
	22-Sep- 2008		Disposal Operations End			
Multibeam bathymetric and sub-bottom surveys conducted 16 October 2008						
Sub-bottom survey conducted 3 December 2008						
Sediment coring survey conducted 13–16 July 2009						

***Disposal # = Order of disposal at specific point.**
GLDD = Great Lakes Dredge & Dock

Table 4-3

Target SPI and PUC Stations at MBDS

Line 0 Survey, 20 June 2008

Station ID	Latitude (N)	Longitude (W)
MBDS01-25SE	42° 25.069'	70° 36.130'
MBDS01-CENTER	42° 25.078'	70° 36.135'
MBDS01-50W	42° 25.077'	70° 36.177'
MBDS01-100W	42° 25.078'	70° 36.213'
MBDS01-150W	42° 25.080'	70° 36.246'
MBDS01-200W	42° 25.081'	70° 36.281'
MBDS01-250W	42° 25.082'	70° 36.320'
MBDS01-300W	42° 25.079'	70° 36.350'
MBDS01-350W	42° 25.077'	70° 36.384'
MBDS01-400W	42° 25.076'	70° 36.419'
MBDS01-500W	42° 25.085'	70° 36.475'
MBDS01-600W	42° 25.082'	70° 36.514'
MBDS01-650W	42° 25.086'	70° 36.545'
MBDS01-700W	42° 25.082'	70° 36.574'
MBDS01-800W	42° 25.084'	70° 36.639'
MBDS01-200N	42° 25.186'	70° 36.140'
MBDS01-250N	42° 25.214'	70° 36.142'
MBDS01-300N	42° 25.239'	70° 36.141'
MBDS01-350N	42° 25.271'	70° 36.141'
MBDS01-400N	42° 25.302'	70° 36.143'
MBDS01-475N	42° 25.340'	70° 36.140'
MBDS01-550N	42° 25.382'	70° 36.143'
MBDS01-650N	42° 25.425'	70° 36.140'

Station ID	Latitude (N)	Longitude (W)
MBDS01-750N	42° 25.473'	70° 36.141'
MBDS01-850N	42° 25.522'	70° 36.142'
MBDS01-950N	42° 25.577'	70° 36.142'
MBDS01-1050N	42° 25.630'	70° 36.142'
MBDS01-1150N	42° 25.687'	70° 36.139'
MBDS11-500N	42° 25.741'	70° 35.533'
MBDS11-550N	42° 25.767'	70° 35.531'
MBDS11-600N	42° 25.791'	70° 35.530'
MBDS11-650N	42° 25.820'	70° 35.530'
MBDS11-700N	42° 25.851'	70° 35.527'
MBDS11-750N	42° 25.881'	70° 35.525'
MBDS11-800N	42° 25.911'	70° 35.523'
MBDS11-850N	42° 25.934'	70° 35.521'
MBDS11-900N	42° 25.964'	70° 35.523'
MBDS11-950N	42° 25.993'	70° 35.525'
MBDS11-1000N	42° 26.022'	70° 35.524'
MBDS11-1050N	42° 26.048'	70° 35.522'
MBDS11-1100N	42° 26.069'	70° 35.524'
MBDS11-1150N	42° 26.100'	70° 35.524'
MBDS11-1200N	42° 26.128'	70° 35.527'
MBDS11-CENTER	42° 25.498'	70° 35.530'
MBDS06-CENTER	42° 25.304'	70° 35.825'

Table 4-3, continued

Line 1 Survey, 11 July 2008

Station ID	Latitude (N)	Longitude (W)	Station ID	Latitide (N)	Longitude (W)
MBDS01-01	42° 24.886'	70° 36.127'	MBDS01-23	42° 24.971'	70° 35.927'
MBDS01-02	42° 24.880'	70° 36.135'	MBDS01-24	42° 24.971'	70° 35.915'
MBDS01-03	42° 24.878'	70° 36.137'	MBDS01-25	42° 24.964'	70° 35.903'
MBDS01-04	42° 24.875'	70° 36.140'	MBDS01-26	42° 24.957'	70° 35.889'
MBDS01-05	42° 24.873'	70° 36.142'	MBDS01-27	42° 24.949'	70° 35.879'
MBDS01-06	42° 24.922'	70° 36.114'	MBDS01-28	42° 24.940'	70° 35.864'
MBDS01-06-1	42° 24.915'	70° 36.108'	MBDS01-29	42° 24.928'	70° 35.855'
MBDS01-07	42° 24.907'	70° 36.100'	MBDS01-30	42° 24.919'	70° 35.841'
MBDS01-09	42° 24.898'	70° 36.094'	MBDS01-31	42° 24.909'	70° 35.822'
MBDS01-10	42° 24.891'	70° 36.088'	MBDS01-32	42° 24.954'	70° 35.999'
MBDS01-11	42° 24.904'	70° 36.073'	MBDS01-33	42° 24.949'	70° 35.989'
MBDS01-12	42° 24.901'	70° 36.066'	MBDS01-34	42° 24.942'	70° 35.978'
MBDS01-13	42° 24.894'	70° 36.059'	MBDS01-35	42° 24.933'	70° 35.971'
MBDS01-14	42° 24.888'	70° 36.054'	MBDS01-36	42° 24.926'	70° 35.965'
MBDS01-15	42° 24.884'	70° 36.040'	MBDS01-37	42° 24.919'	70° 35.956'
MBDS01-16	42° 24.879'	70° 36.031'	MBDS01-38	42° 24.912'	70° 35.946'
MBDS01-17	42° 24.869'	70° 36.021'	MBDS01-39	42° 24.906'	70° 35.940'
MBDS01-18	42° 24.858'	70° 36.013'	MBDS01-40	42° 24.900'	70° 35.930'
MBDS01-19	42° 24.848'	70° 36.003'	MBDS01-41	42° 24.893'	70° 35.924'
MBDS01-20	42° 24.837'	70° 35.995'	MBDS01-42	42° 24.886'	70° 35.914'
MBDS01-21	42° 24.984'	70° 35.942'	MBDS01-43	42° 24.876'	70° 35.901'
MBDS01-22	42° 24.977'	70° 35.931'	MBDS01-44	42° 24.870'	70° 35.885'

Table 4-3, continued

Lines 2-6 Survey, 29 August 2008

Station ID	Latitude (N)	Longitude (W)	Station ID	Latitude (N)	Longitude (W)
MBDS-02-01	42° 24.839'	70° 36.036'	MBDS-02-35	42° 25.311'	70° 35.675'
MBDS02-02	42° 24.839'	70° 36.041'	MBDS-02-36	42° 25.298'	70° 35.648'
MBDS-02-03	42° 24.832'	70° 36.046'	MBDS-02-37	42° 25.284'	70° 35.625'
MBDS-02-04	42° 25.017'	70° 36.206'	MBDS-02-38	42° 25.274'	70° 35.609'
MBDS-02-05	42° 25.010'	70° 36.210'	MBDS-02-39	42° 25.263'	70° 35.588'
MBDS02-06	42° 25.006'	70° 36.114'	MBDS-02-40	42° 25.215'	70° 35.517'
MBDS-02-07	42° 24.992'	70° 36.123'	MBDS-02-41	42° 25.212'	70° 35.466'
MBDS-02-08	42° 24.985'	70° 36.115'	MBDS-02-42	42° 25.210'	70° 35.493'
MBDS-02-09	42° 24.974'	70° 36.108'	MBDS-02-43	42° 25.210'	70° 35.533'
MBDS-02-10	42° 24.965'	70° 36.099'	MBDS-02-44	42° 25.203'	70° 35.562'
MBDS-02-11	42° 24.953'	70° 36.089'	MBDS-02-45	42° 25.209'	70° 35.588'
MBDS-02-12	42° 24.946'	70° 36.076'	MBDS-02-46	42° 25.217'	70° 35.523'
MBDS-02-13	42° 24.939'	70° 36.057'	MBDS-02-47	42° 25.227'	70° 35.530'
MBDS-02-14	42° 24.929'	70° 36.041'	MBDS-02-48	42° 25.237'	70° 35.546'
MBDS-02-15	42° 24.914'	70° 36.020'	MBDS-02-49	42° 25.246'	70° 35.557'
MBDS-02-16	42° 24.913'	70° 35.989'	MBDS-02-50	42° 25.252'	70° 35.567'
MBDS-02-17	42° 24.918'	70° 35.975'	MBDS-02-51	42° 25.225'	70° 35.460'
MBDS-02-18	42° 24.918'	70° 35.956'	MBDS-02-52	42° 25.267'	70° 35.452'
MBDS-02-19	42° 24.902'	70° 35.949'	MBDS-02-53	42° 25.290'	70° 35.460'
MBDS-02-20	42° 24.884'	70° 35.944'	MBDS-02-54	42° 25.129'	70° 35.407'
MBDS-02-21	42° 24.877'	70° 35.939'	MBDS-02-55	42° 25.128'	70° 35.427'
MBDS-02-22	42° 24.865'	70° 35.936'	MBDS-02-56	42° 25.087'	70° 35.448'
MBDS-02-23	42° 24.857'	70° 35.927'	MBDS-02-57	42° 25.067'	70° 36.054'
MBDS-02-24	42° 24.844'	70° 35.931'	MBDS-02-58	42° 25.078'	70° 36.068'
MBDS-02-25	42° 24.851'	70° 35.952'	MBDS-02-59	42° 25.088'	70° 36.080'
MBDS-02-26	42° 24.861'	70° 35.966'	MBDS-02-60	42° 25.096'	70° 36.084'
MBDS-02-27	42° 24.871'	70° 35.956'	MBDS-02-61	42° 25.103'	70° 36.092'
MBDS-02-28	42° 24.843'	70° 35.828'	MBDS-02-62	42° 25.112'	70° 36.100'
MBDS-02-29	42° 24.850'	70° 35.844'	MBDS-02-63	42° 25.118'	70° 36.109'
MBDS-02-30	42° 25.215'	70° 35.830'	MBDS-02-64	42° 25.123'	70° 36.113'
MBDS-02-31	42° 25.201'	70° 35.803'	MBDS-02-65	42° 25.133'	70° 36.117'
MBDS-02-32	42° 25.190'	70° 35.784'	MBDS-02-66	42° 25.141'	70° 36.123'
MBDS-02-33	42° 25.178'	70° 35.768'	MBDS-02-67	42° 25.145'	70° 36.127'
MBDS-02-34	42° 25.164'	70° 35.757'	MBDS-02-68	42° 25.155'	70° 36.132'

Coordinate System: NAD 83

Table 4-4
Sediment Core Targets at MBDS

Station ID	Zone	Latitude (N)	Longitude (W)
1	Ambient	42° 25.356'	70° 36.342'
2	Ambient	42° 25.469'	70° 36.193'
3	Ambient	42° 25.556'	70° 36.043'
4	Ambient	42° 25.643'	70° 35.907'
5	Ambient	42° 25.734'	70° 35.754'
6	Single Disposal on Ambient	42° 25.116'	70° 36.099'
7	Single Disposal on Ambient	42° 25.109'	70° 36.092'
8	Single Disposal on Ambient	42° 25.101'	70° 36.082'
9	Single Disposal on Ambient	42° 25.455'	70° 35.628'
10	Single Disposal on Ambient	42° 25.447'	70° 35.615'
11	Single Disposal on Ambient	42° 25.438'	70° 35.601'
12	Flank on Ambient	42° 25.145'	70° 36.131'
13	Flank on Ambient	42° 25.134'	70° 36.120'
14	Flank on Ambient	42° 25.124'	70° 36.107'
15	Flank on Ambient	42° 25.090'	70° 36.072'
16	Flank on Ambient	42° 25.080'	70° 36.060'
17	Flank on Ambient	42° 25.469'	70° 35.652'
18	Flank on Ambient	42° 25.463'	70° 35.641'
19	Flank on Ambient	42° 25.430'	70° 35.586'
20	Multiple Flank on Ambient	42° 24.953'	70° 36.089'
21	Multiple Flank on Ambient	42° 24.941'	70° 36.069'
22	Single Disposal on Flank	42° 24.866'	70° 36.021'
23	Single Disposal on Flank	42° 24.877'	70° 36.001'
24	Single Disposal on Flank	42° 24.888'	70° 35.982'
25	Single Disposal on Flank	42° 24.899'	70° 35.963'
26	Single Disposal on Flank	42° 24.909'	70° 35.947'
27	Single Disposal on Flank	42° 24.918'	70° 35.930'
28	Single Disposal on Flank	42° 24.928'	70° 35.914'
29	Single Disposal on Flank	42° 24.940'	70° 35.891'
30	Single Disposal on Ambient	42° 25.102'	70° 36.100'
31	Single Disposal on Ambient	42° 25.113'	70° 36.083'
32	Single Disposal on Ambient	42° 24.886'	70° 35.966'
33	Single Disposal on Ambient	42° 24.901'	70° 35.987'
34	Single Disposal on Ambient	42° 24.934'	70° 36.052'
35	Flank on Ambient	42° 24.958'	70° 36.099'
36	Single Disposal on Ambient	42° 25.442'	70° 35.621'
37	Single Disposal on Ambient	42° 25.452'	70° 35.607'

Coordinate System: NAD 83

Table 4-5

Summary of Core Analysis Parameters

GeoTek™ Sensor Measurements	
Bulk density	From gamma density measurements
High resolution photography	
Magnetic susceptibility	Iron content/profile information
Resistivity	Sediment porewater or porosity
P-Wave velocity	Also sediment density
Discrete Measurements	
Shear	Torvane shear measurements
Density	
Moisture	
Grain size	
Atterberg limits	
CHN analysis	
^{210}Pb analysis	
Specific gravity	
Consolidation	Selected cores only

5.0 DEMONSTRATION RESULTS

Between June and October 2008 approximately 380,000 m^3 of dredged material, consisting mostly of Boston Blue Clay, was deposited along Lines 0–6 as part of the demonstration project at the IWS (Table 4-2, Figure 4-1). Additional maintenance material from the harbor dredging project was disposed at the MBDS buoy and along Lines 7–9 (Figure 4-1). Because of the difference in sediment type, Lines 7–9 were not evaluated further as part of the demonstration project. Monitoring surveys were conducted at various times during the disposal period in 2008 (Table 4-2), and a sediment coring survey followed in July 2009.

5.1 Overview of Study Tools and Their Application

As will be detailed later in the report, the study involved multiple surveys at the project site between the major series of placement events discussed above. These surveys used a variety of tools to address the study questions. In many cases, multiple tools were applied to the individual questions in order to provide several lines of evidence to support interpretation. The study questions, the tools used to address each one, and how the resulting data were used are provided in Table 5-1.

5.2 Bathymetry and Backscatter

Four separate multibeam bathymetric surveys were conducted over the RDA, coinciding with the completion of specific disposal events during the course of the demonstration project (Table 4-2). The objective of these surveys was to document the topography of the seafloor throughout the different phases of the experiment. The June and October 2008 surveys provided the most insight into the performance of the demonstration project and are described in detail below.

5.2.1 June 2008 Survey

The first bathymetric survey of the 2008 disposal period was conducted 20 June over a 2000 x 500 m area in the northern portion of the RDA (Figure 4-5). The extent and timing of this survey was designed to capture the disposals along Line 0, which consisted of single disposal events on the ambient seafloor. The resulting bathymetric map of Line 0 showed 11 individual impact craters along the target line, one crater approximately 125 m north of the line, and two less obvious craters 250 and 300 m west of the beginning of the line (Figure 5-1). These craters near Line 0 were believed to be the result of off-target disposals from other projects that were intended for the MBDS buoy and were not part of the demonstration project.

Crater diameters along Line 0 ranged from 44–93 m from rim to rim, with an average diameter of approximately 73 m and a coefficient of variation of 17%. Crater depths (calculated as the difference between the baseline bathymetric depth [2007] and the post placement depth) were proportionally more variable with vertical impacts ranging from 0 to over 1 meter (Figure 5-2).

The backscatter map from the June survey revealed areas with surface texture that reflected more backscatter strength than the ambient surface. These areas formed a nearly continuous halo around the combined impact areas extending approximately 150 m away from the impact points (Figure 5-3). Notably, the three anomalous craters visible in the bathymetry did not have backscatter halos. These impact areas were assumed to be older than demonstration disposal activity with possibly different material properties. A contour map of backscatter signal strength confirmed that the highest backscatter signal (-13 to -15 dB) was found in the impact areas themselves with concentric rings of lesser signal strength extending away from the crater rims (Figure 5-4). Backscatter signal strength at the outer extent of the survey reached -31 dB. Side-scan sonar data from the same survey showed a similar pattern and distribution of surface roughness.

5.2.2 October 2008 Survey

The final bathymetric survey of the demonstration project was conducted 16 October 2008, approximately three weeks after the completion of all disposal activity at the RDA. This survey covered a 1500 x 1800 m area that included Lines 0–9 (Figure 4-5). The resulting bathymetric map confirmed the dimensions of the Line 0 craters and documented the size of the Line 1 craters and the disposal berm created at the Lines 2–6 complex (Figure 5-5).

A depth difference map was created to evaluate changes in RDA topography since the 2007 baseline survey (Figure 5-6). The expected error for the surveys was calculated, based on equipment and site depth, as ±0.2 m per survey. The resulting depth difference map showed small areas of sediment compaction or scouring at the impact points along Line 0 in excess of 0.5 m. Isolated patches of sediment loss and gain were also noted on Line 1 along with up to 4 m of sediment accumulation at Lines 2–6.

The backscatter map from the October 2008 survey showed the same patterns of increased backscatter intensity radiating out from the impact centers along Line 0 that were observed in the June dataset (Figure 5-7). There did not appear to be any subsequent reduction of the backscatter intensity in the four months that had passed between surveys. A similar pattern and extent of increased backscatter intensity was noted at the impact points along Line 1 and in the triangular area between Line 1 and Line 6, however, Lines 3–5, one impact area on Line 1, and Craters A/B did not show the same level of backscatter intensity. This was confirmed by a contoured map of backscatter signal strength across the entire site (Figure 5-8). Note that disposal of maintenance material at Lines 7–9 did result in increased backscatter intensity around the disposal points, although impact craters are much less pronounced (Figure 5-7).

5.3 Tracking Material Placement

The ability to accurately direct the placement of material was tracked primarily through the expression of disposal craters in the bathymetric records described above. Comparing this data against the ADISS disposal targets provided to the tug operators (Figure 4-3) allowed for the calculation of placement accuracy. This exercise was most applicable to the disposals along Lines 0 and 1 where the individual impact points could be clearly identified in the bathymetric data. On these disposal lines the accuracy of placement was generally less than 100 m and averaged 62 m across both lines (Table 5-2 and Figure 5-9). This is considered particularly accurate placement given the dimensions of the barges themselves in relation to the observed offset (Figure 5-10).

5.4 Sub-bottom Profiling

On 3 December 2008 a towed sub-bottom profiling system was used to acquire stratigraphic data along a series of lines which intersected disposal regions of particular interest (Figure 4-7). Surficial features of the sub-bottom data showed strong alignment with multibeam data from the October survey and the system was able to penetrate 15–30 m beneath the sediment surface revealing depth to deeper acoustic reflectors that varied across the survey area (Figure 5-11).

The sub-bottom data were used to evaluate the extent of impact on the original ambient sediment surface from disposal events. Over some disposal impact points the acoustic signal suggested that the original ambient sediment surface remained partially intact and could be traced beneath the overlying dredged material. For example, the original ambient surface was detectable throughout Crater 1 on Line 0, which experienced over 1 m of vertical impact (Figure 5-12). At other disposal points the ambient surface was only perceptible over portions of the sub-bottom profile with the signal becoming discontinuous under the impact points themselves (Figure 5-13). The sub-bottom profile from the Lines 2–6 complex showed a distinct relic ambient surface, even under 4 m of dredged material (Figure 5-14).

5.5 Sediment-Profile and Plan-View Imaging

Three separate SPI surveys were conducted as part of the demonstration project (Table 4-2). The June survey was designed to document the lateral extent of dredged material distribution around Line 0 (Figure 5-15). Dredged material thickness was as high as 10.1 cm in the immediate vicinity of the impact points, and trace amounts of dredged material (< 0.1 cm) were present as much as 1 kilometer away from the impact point.

The two subsequent SPI surveys focused on the immediate disposal areas. Intact clay blocks were visible in both plan-view and SPI images of the impact sites, with smaller clay clumps present in SPI stations 100–200 m from the impact point, and isolated clay clasts present on the surface 200–300 m from the impact point (Figure 5-16).

The thickness of dredged material varied between craters and disposal lines but was 10 cm or greater for the majority of the impact points (Figure 5-17). SPI camera penetration was limited by the presence of consolidated blocks of clay in the immediate impact area, and dredged material often extended beyond the camera depth of penetration. This limited the quantitative evaluation of dredged material thickness at the impact points through SPI analysis which was more suitable for defining the flank and apron deposits.

5.6 Sediment Coring

A combination of box cores and piston cores was collected at five ambient stations as part of the demonstration project (Figure 4-8). These cores were analyzed for comparison of ambient conditions with sediment cores from the demonstration project. Due to the need for penetration through meters of dredged material, a piston core was used at the 32 stations across several disposal locations in the RDA (Table 5-3 and Figure 5-18). Comprehensive plots, including core images and selected GeoTek™ and laboratory measurements, are compiled in Appendix F.

5.6.1 Geotek™ Sensors

The following parameters were analyzed using the GeoTek™ sensors; magnetic susceptibility, bulk density, P-wave, and resistivity. P-wave measurements were interrupted by voids or gas bubbles and resistivity measurements suffered from significant edge-effects. Therefore, P-wave and resistivity data are not discussed further.

5.6.1.1 Magnetic Susceptibility

Ambient piston cores showed relatively high (>10 international standard units [SI]) magnetic susceptibility/iron bearing particles in the upper 30 cm of sediment (Appendix F). In the deeper layers of the core the susceptibility stabilized at approximately 5 SI. Magnetic susceptibility in the short box cores may have been influenced by sensor edge effects and were not used to determine likely ambient values.

Magnetic susceptibility profiles of cores collected from the demonstration area were highly variable due to the range of sediment layers present including dredged material, ambient sediment, and mixed layers. In segments where Boston Blue Clay was present, the susceptibility was typically above 40 SI and often exceeded the sensor range, as in the upper 15 cm of Core 7-1 (Figure 5-19). In the 10 cm below the clay layer of the same core the susceptibility became erratic with values jumping from 25 SI to more than 40 SI within a few centimeters of sediment (Figure 5-19). This is likely representative of a mixing zone of dredged material and ambient sediment. Below this variable signal the magnetic susceptibility stabilized at approximately 5 SI for the remainder of the core (Figure 5-19), similar to the profile observed in ambient sediments greater than 30 cm deep.

5.6.1.2 Bulk Density

Bulk density measurements of ambient cores were also sufficiently sensitive to be used in evaluating the core profiles. The bulk density of soft surface sediment increased sharply within the first 5 cm of depth (Appendix F). This was distinguished from the consistent density values (1.5–1.7 $g \cdot cm^{-3}$) of the more densely packed sediment observed in the deeper layers of the ambient cores.

This ambient-like bulk density profile was visible within several of the cores collected in the demonstration area, including Cores 12-1 and 13-1 (Appendix F). However, density measurements from other demonstration area stations showed irregularities in the profile (Core 17-1, Appendix F) or lacked the soft surficial sediment layer (Core 30-1, Appendix F).

5.6.2 Laboratory Analysis

Shear strength and ^{210}Pb activity data provided the most information among the discrete laboratory measurements. Grain size and CHN measurements from the surface of cores could not be distinguished from sediments at depth so these data were not evaluated further (Appendix G and H). Ambient sediment consisted of 80–90 % fine material (as silt and clay).

5.6.2.1 Shear Strength

A torvane penetrometer was used to measure the shear strength of sediment intervals for ambient and demonstration area cores that were not dominated by Boston Blue Clay (Appendix D). Ambient cores showed a predictable increase in shear strength with depth (Figure 5-20). Surficial segments (0–10 cm) had soft/low shear values between 0.005 and 0.03 $kg \cdot cm^{-2}$ (0.07–0.43 PSI) while deeper sediments (120 cm) had shear values as high as 0.075 $kg \cdot cm^{-2}$ (1.1 PSI). This correlation of shear strength to sediment depth in ambient cores allowed for the comparison of demonstration area shear profiles with expected ambient values.

As with magnetic susceptibility, shear measurements from demonstration area cores were variable and reflected a range of sediment types and conditions. Shear profiles for some cores showed increases in strength with depth and shear values similar to those seen in ambient profiles (Core 12-1, Figure 5-20). Other cores showed an ambient-like trend with depth but with surficial shear values that were characteristic of stronger, deeper ambient sediments (Cores 10-1 and 15-1, Figure 5-20). These values may be indicative of areas where surficial material had been scoured away by disposal events exposing deeper sediments at the surface. Other cores showed apparent discontinuities in shear strength profiles (Core 18-1, Figure 5-20), suggesting highly mixed or recently disturbed sediment over a more stable sediment column.

5.6.2.2 ^{210}Pb Profiles

The radioactive isotope ^{210}Pb is one of the last elements created by the decay of ^{238}U. It forms naturally in rocks and sediments containing ^{238}U and in the atmosphere as a byproduct of ^{222}Rn gas. Atmospheric ^{210}Pb settles onto the earth's surface and accumulates in soils, sediments, and glacial ice. In undisturbed sediments the radioactive isotope of lead decays to the stable form of ^{206}Pb with a half life of 22.3 years. Sediment horizons have reached "supported" ^{210}Pb levels when atmospheric contribution and biological down-mixing of ^{210}Pb enriched sediments is counter-balanced by radioactive decay. In "unsupported" sediment layers ^{210}Pb activities remain in excess of background levels due to input from atmospheric deposition and biological down-mixing.

Ambient ^{210}Pb activity data were sufficiently sensitive to establish a vertical profile and to distinguish between "unsupported" and "supported" sediment horizons. "Supported" ^{210}Pb activities were reached in the ambient cores at a depth of approximately 35 cm (Figure 5-21). This depth is a conservative estimate based on the relative error associated with the ^{210}Pb measurements. This relationship allowed for source determination of sediment from demonstration area stations as either "unsupported" ^{210}Pb levels representing surficial material (<35 cm), or "supported" ^{210}Pb levels originating from layers deeper than 35 cm (Appendix E).

5.6.2.3 Consolidation

Results from one-dimensional consolidation testing and consolidated un-drained triaxial compression testing provide an opportunity for evaluating potential consolidation scenarios (Appendix L). Specifically, a theoretical consolidation curve can be prepared using the ambient core data (Stations 2, 3, and 5) which can be compared with the demonstration area data (Line 0 Craters 1 and 9, and Line 1 Craters A and B) to estimate the ambient and dredged sediment consolidation component of the elevation changes measured at the disposal sites.

5.7 Crater Modeling Tool

The modeling tool that was developed based on published laboratory coefficients and empirical data from this demonstration project provided a means to analyze potential crater formations from different material placement scenarios at the IWS.

5.7.1 Particle Analysis

The first phase of the screening tool considered how crater diameters will change due to the shape and size of the descending particles. Spherical and cubic clay chunks with diameters or edge lengths of 0.25, 0.5, 1.0 and 2.0 meters were considered. Round chunks exhibited a higher terminal velocity due to their reduced drag, while a cubic chunk with a comparable edge length had greater mass. Both mass and velocity determined the kinetic energy at impact, which in turn dictated the size of the resulting crater.

The results showed that the difference in crater dimensions between similarly sized spherical and cubic particles was small over the range of sizes considered. The craters formed from cubic chunks were slightly larger than the craters from spherical chunks, due to the greater kinetic energy caused by the greater mass. For example, the impact crater from a

2 m cube was 20% wider than the crater caused by a sphere with a diameter of 2 m. As would be expected, crater diameters and depths increased with the size of the particle. Crater diameters ranged from 0.5 to 4.3 meters while crater depths ranged from 0.1 to 0.9 meters for the size particles that were modeled with this tool (Appendix M).

5.7.2 Sediment Cloud Analysis

After reviewing the physics involved with the impact of a cloud of sediment on the seafloor it became clear that the processes involved were different than those for a particle impact and would need to be treated differently in the model. In particular, the density of the cloud was less than the density of the target seafloor material, and the cloud was deformable, as opposed to a solid particle. This led to the model under predicting the diameter and depth of the resulting crater. Reviewing the crater dimensions from the demonstration project lead to a revision in the model scaling factors in order to address this change in the cratering process.

A series of twelve simulations were modeled with the screening tool to capture typical placement scenarios at the IWS including expected variations in dredged material characteristics (percent solids, percent water, void space, and grain size) and documented variations in placement conditions (barge speed, current speed, and release time). The average diameter of individual craters formed on the ambient seafloor during the demonstration project was 72.8 m (Table 5-2) compared to the average diameter from the raw model output of 35.7 m. This was corrected by increasing the general scaling coefficient to calibrate the model assumptions with the demonstration project empirical data.

Similarly, the depths of the demonstration project craters and the model craters were compared as well. However, since the depth of the crater is critical to determining the potential for disturbance to the underlying sediment or waste containers, the average demonstration project crater depth (0.33 m) was compared to the average model depth minus one standard deviation. This conservative approach resulted in a scaling relationship between the modeled crater depth and diameter of $Depth_{crater} = Diameter_{crater}/220$. When applied to the model simulations of typical placement scenarios the output craters were approximately 74 m in diameter and 0.34 m in depth, with a slight increase due to the presence of very dense Boston Blue Clay or cobbles (Figure 5-22 and Appendix M).

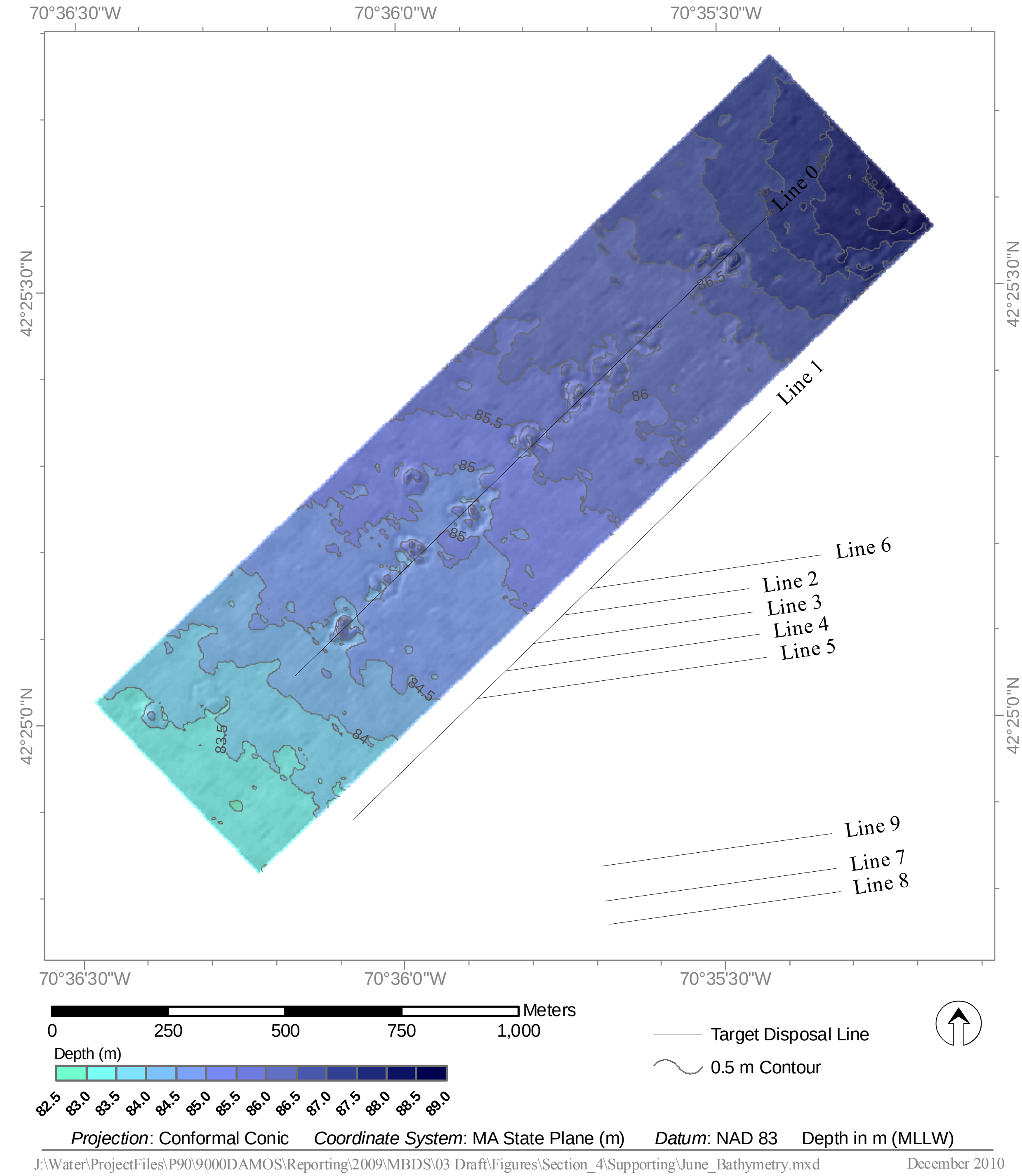

Figure 5-1: June 2008 bathymetry following single placements along Line 0

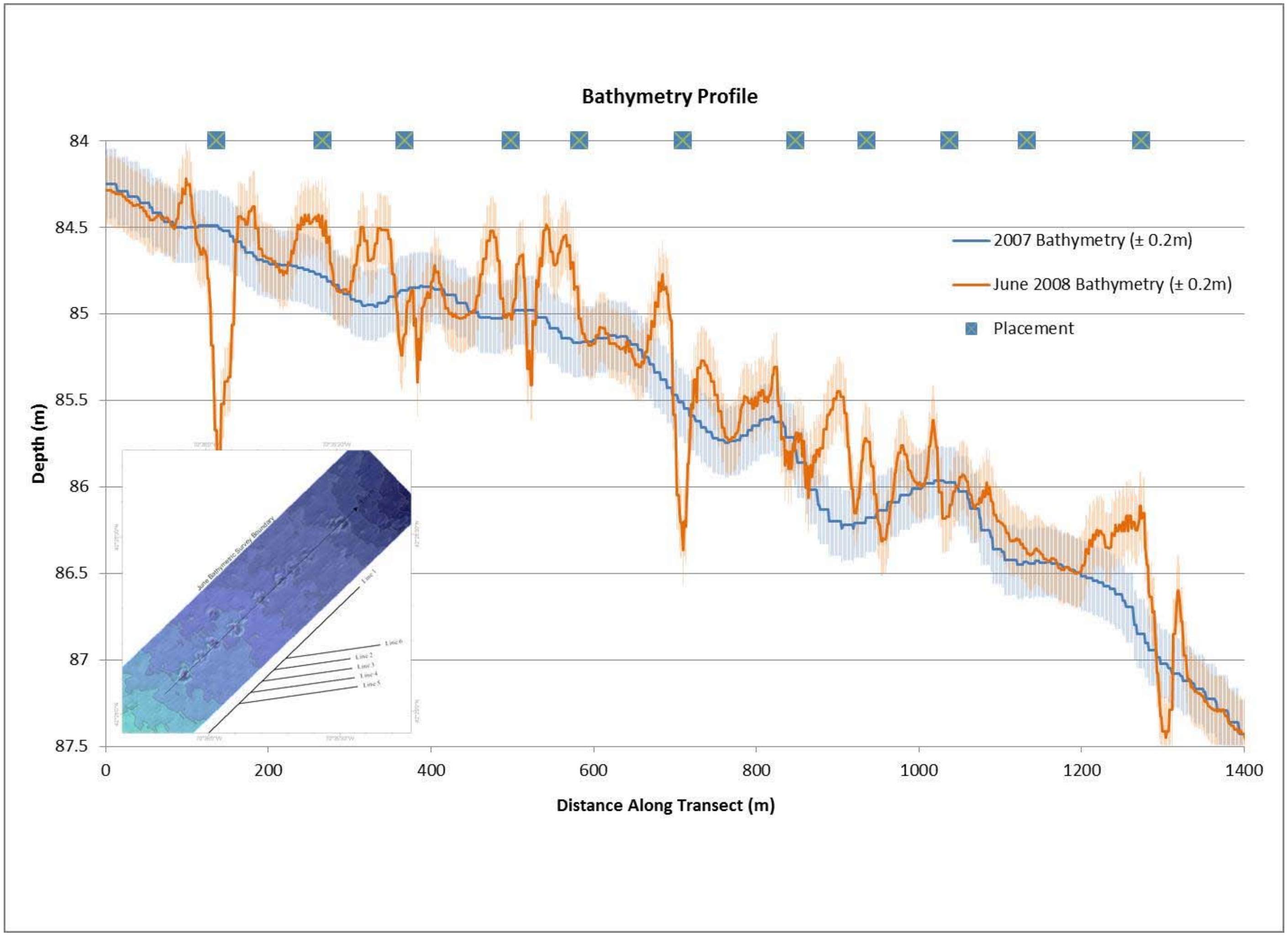

Figure 5-2: Bathymetric profile along Line 0 comparing 2007 baseline and 2008 post placement surveys

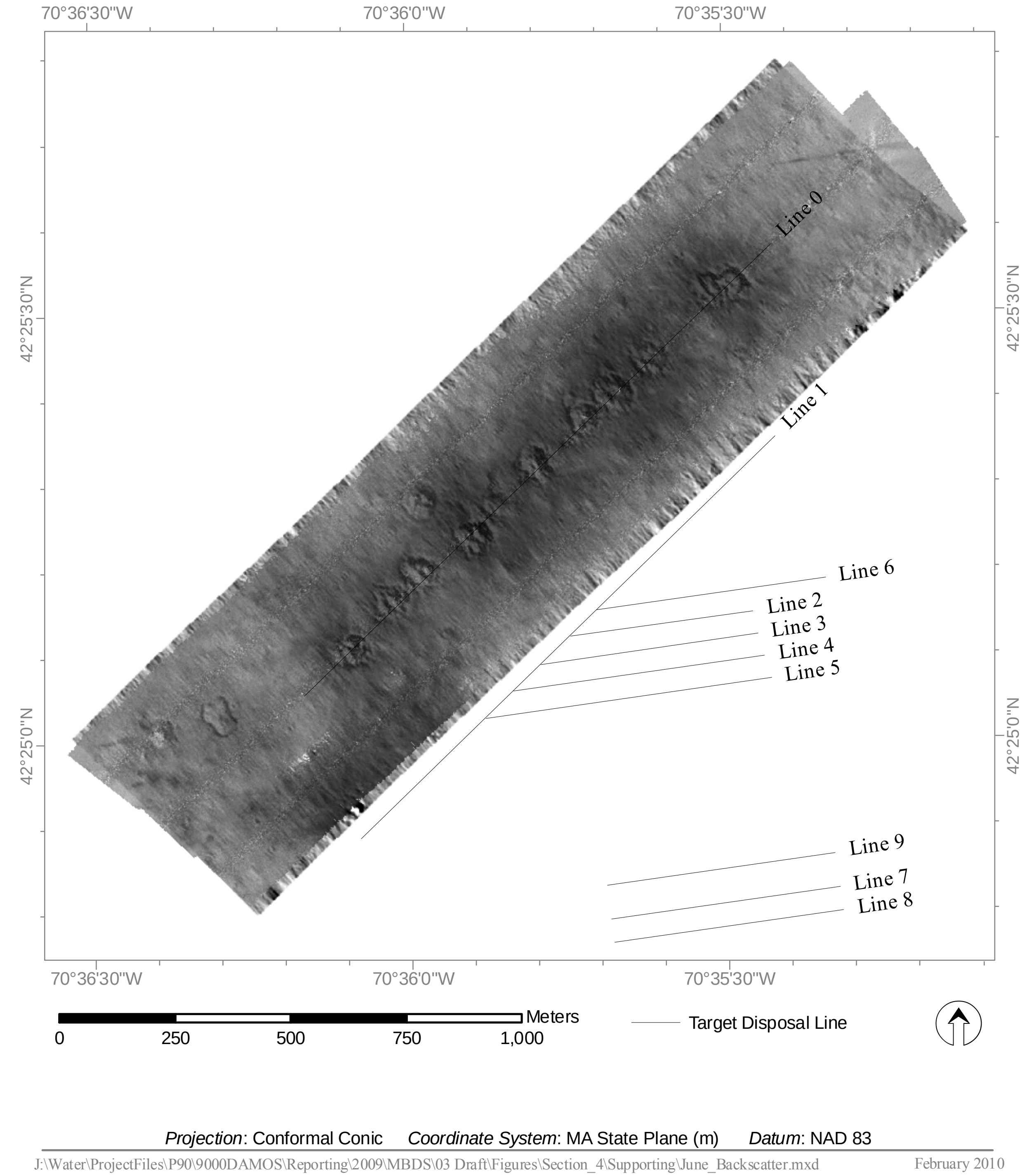

Figure 5-3: June 2008 backscatter following single placements along Line 0

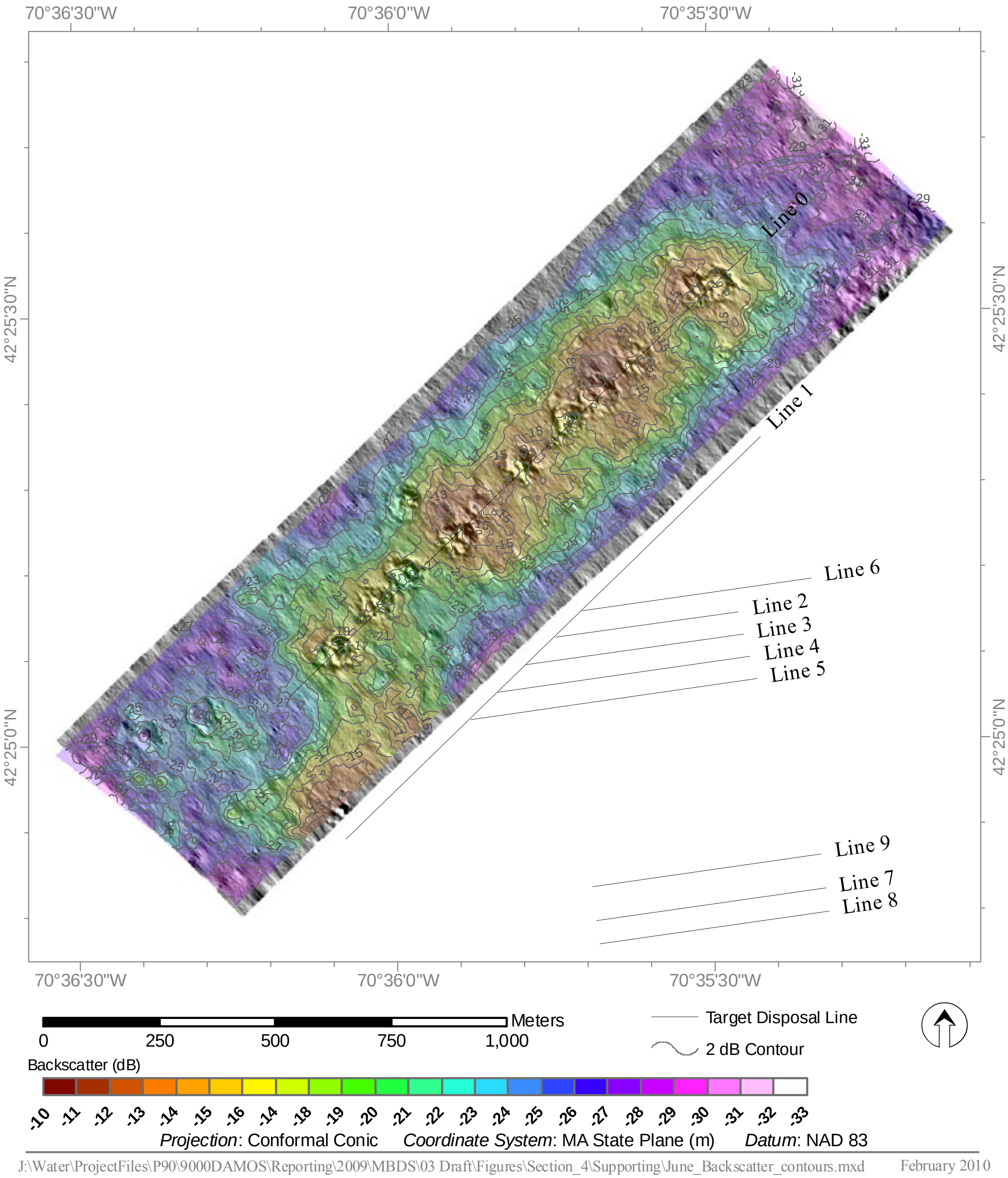

Figure 5-4: June 2008 contoured backscatter following single placements along Line 0

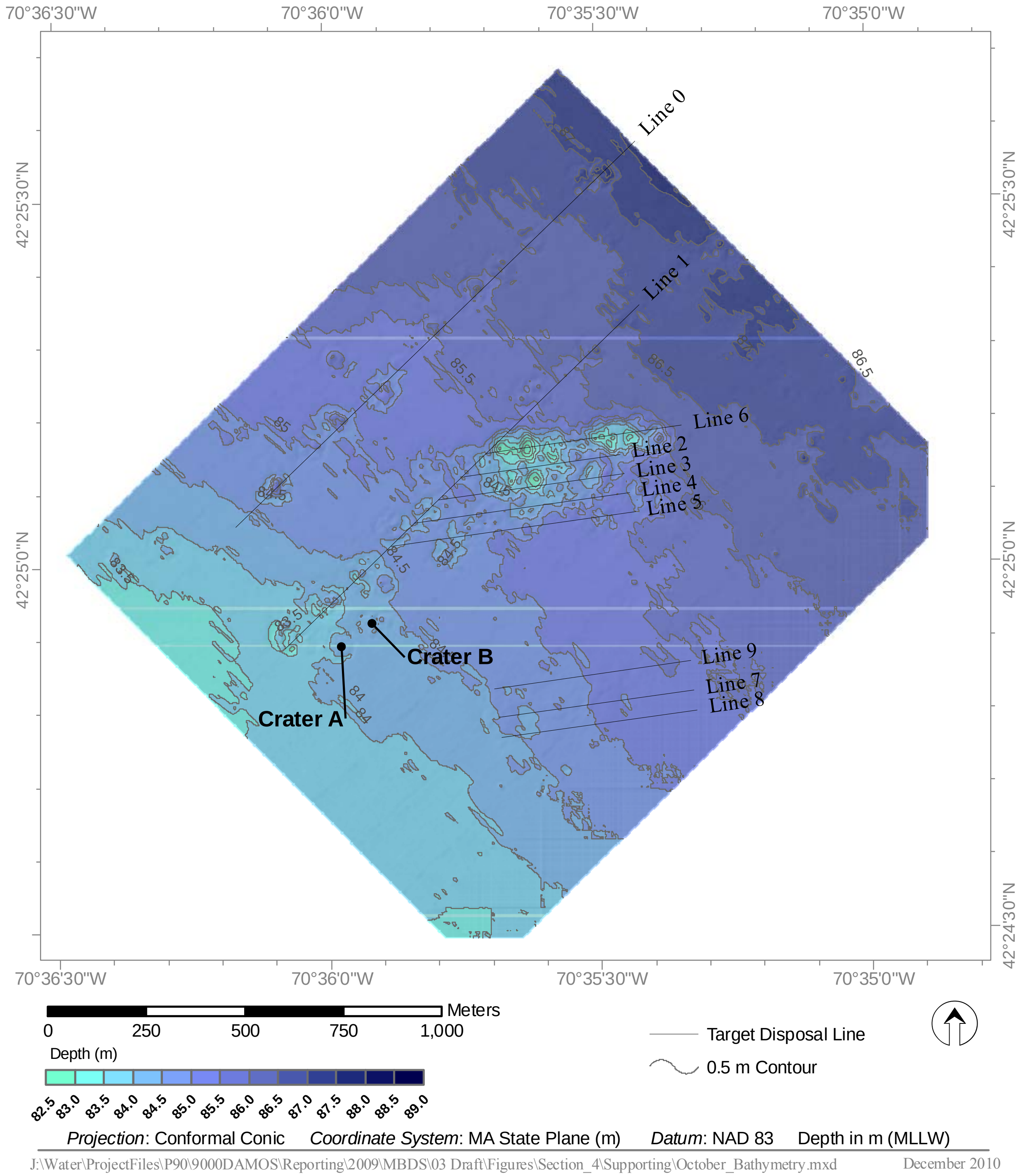

Figure 5-5: October 2008 bathymetry following completion of placement at the RDA

Figure 5-6: Depth difference between the 2007 baseline survey and the October 2008 survey following completion of placement at the RDA

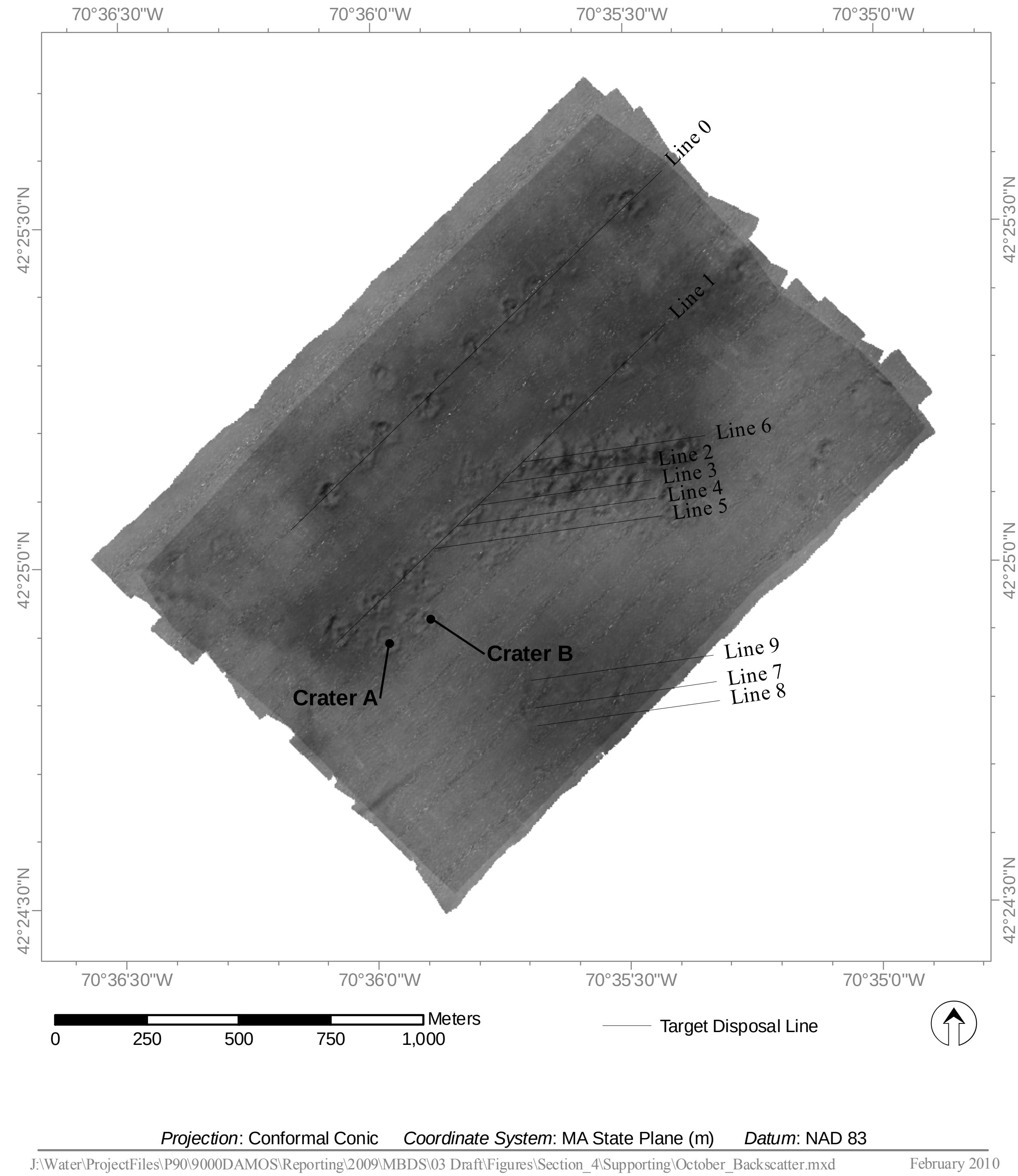

Figure 5-7: October 2008 backscatter following completion of placement at the RDA

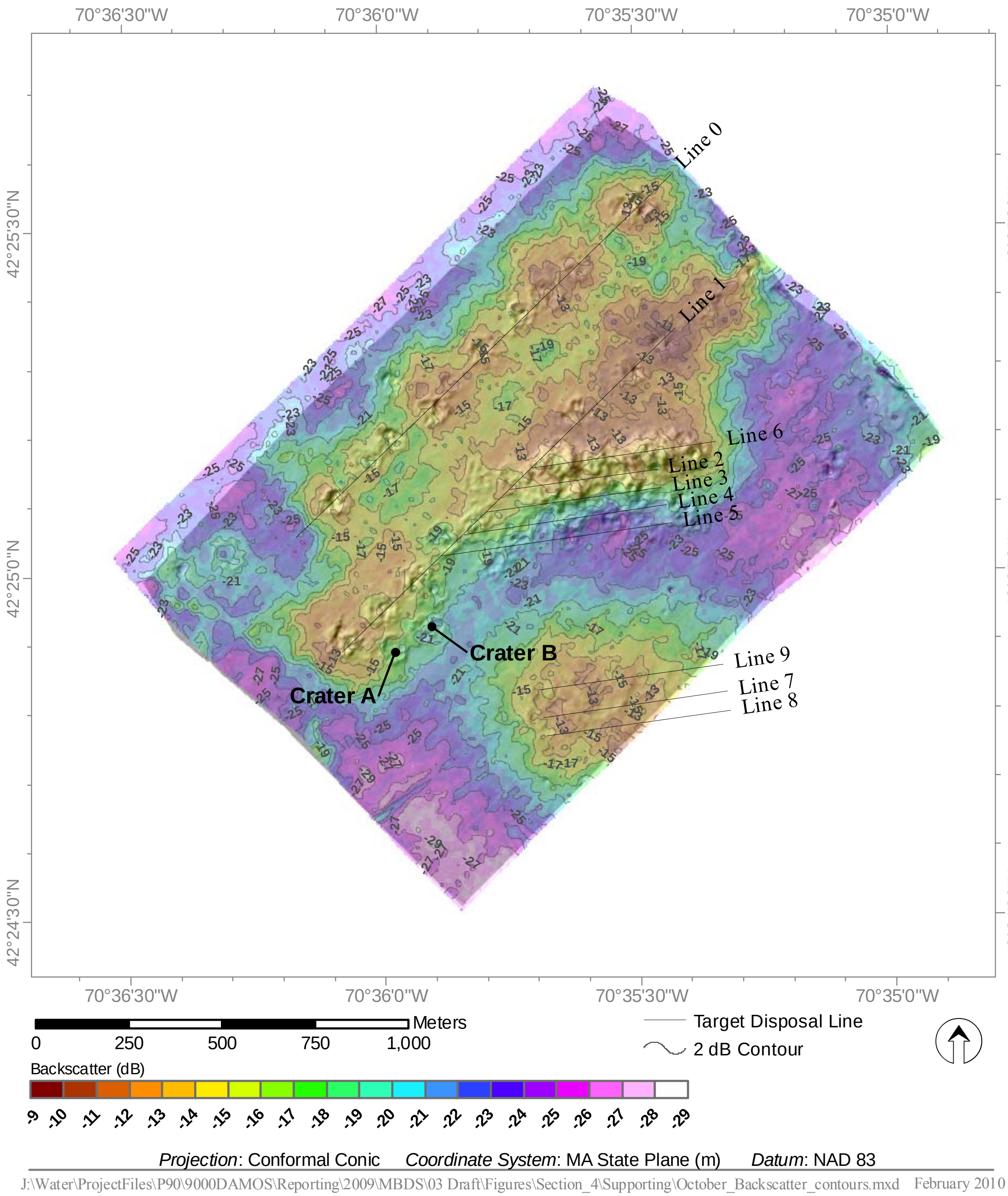

Figure 5-8: October 2008 contoured backscatter following completion of placement at the RDA

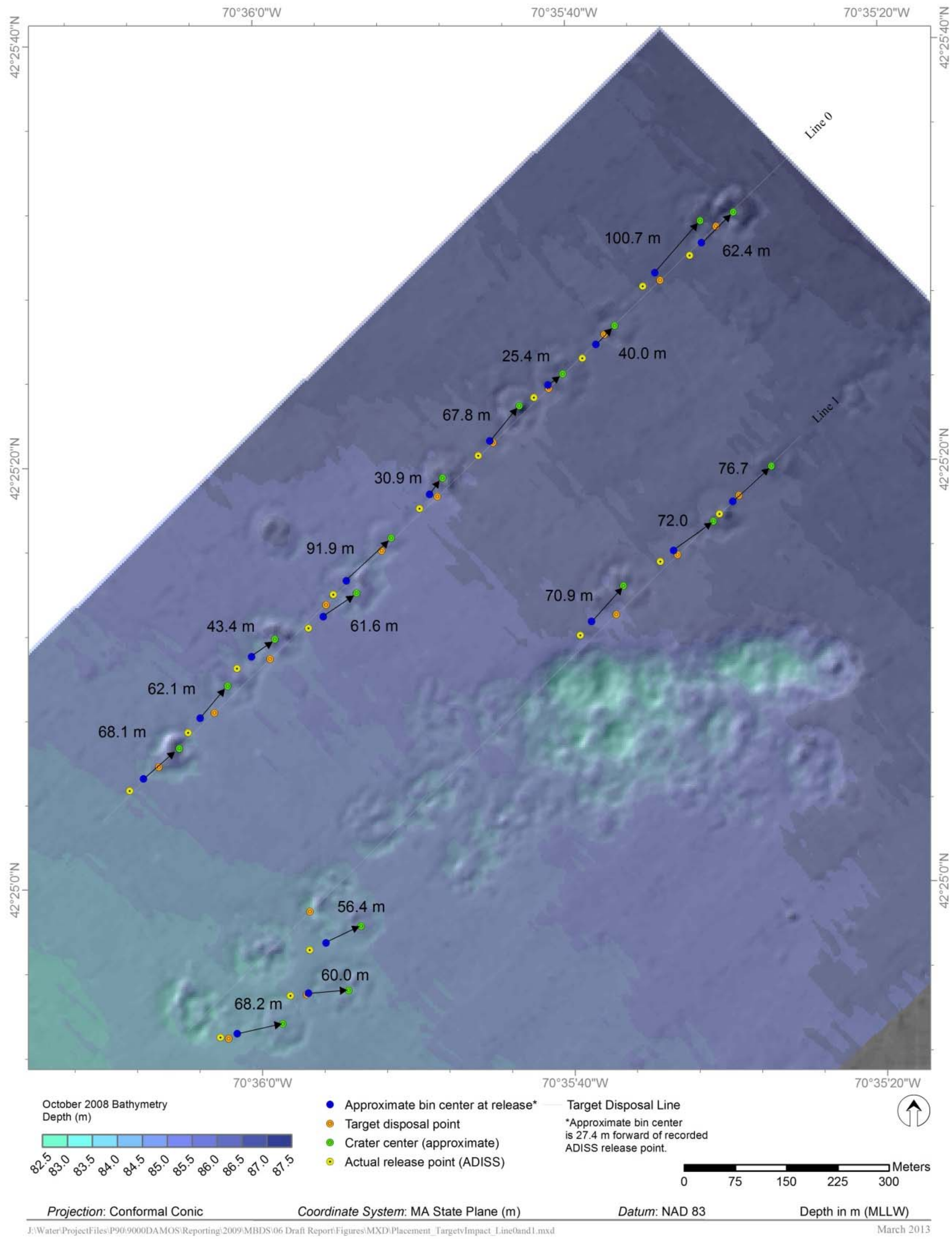

Figure 5-9: Comparison of target placement locations, logged barge release points, and location of impacts on the seafloor for individual placement events

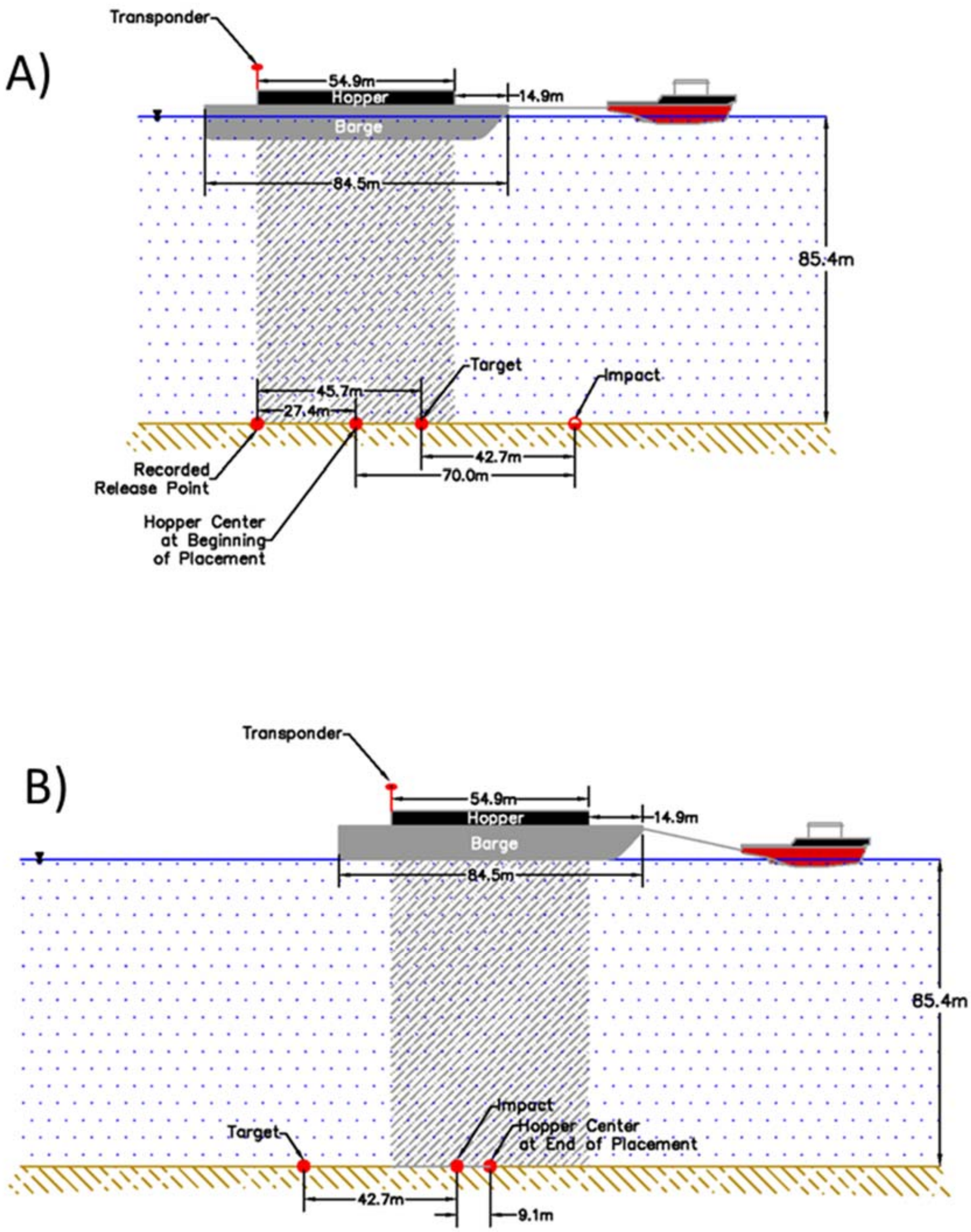

Figure 5-10: Approximate scale of disposal barge and RDA water column showing dimensions of material release footprint for a) barge at the beginning of placement and b) barge at the end of placement

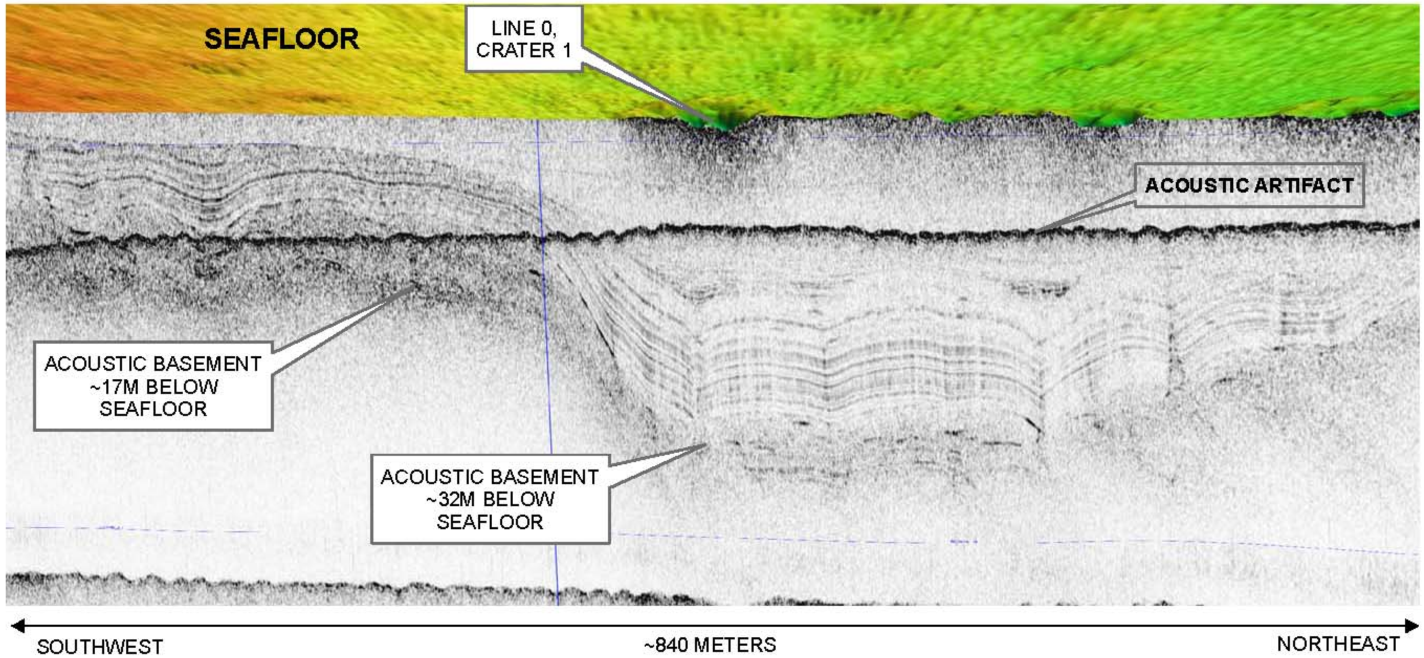

Figure 5-11: Sub-Bottom profile overview for 2008 survey along Line 0

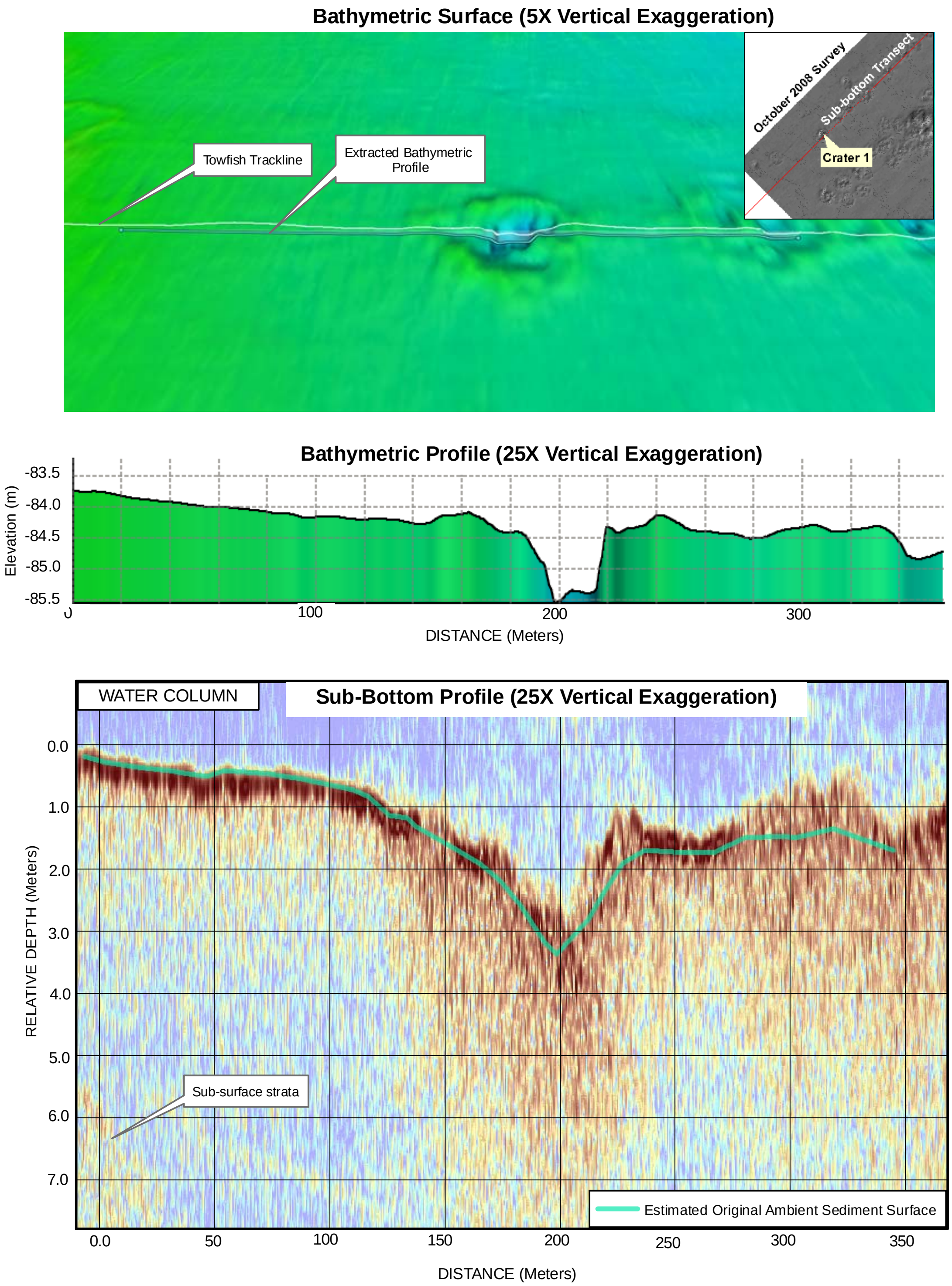

Figure 5-12: 2008 bathymetry and sub-bottom profile of crater 1 on Line 0

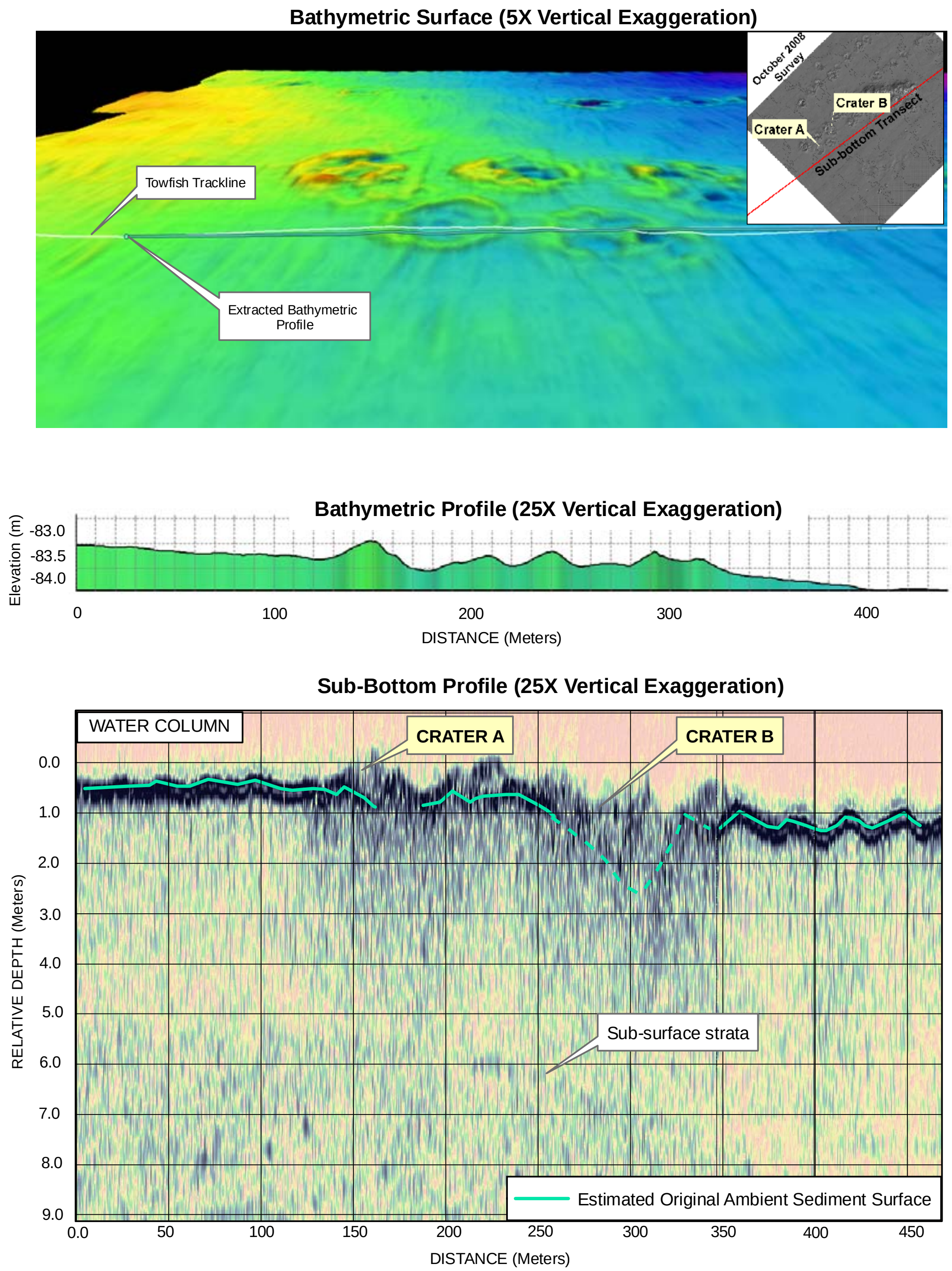

Figure 5-13: 2008 bathymetry and sub-bottom profile of craters A and B (single placements on a flank offset from Line 1)

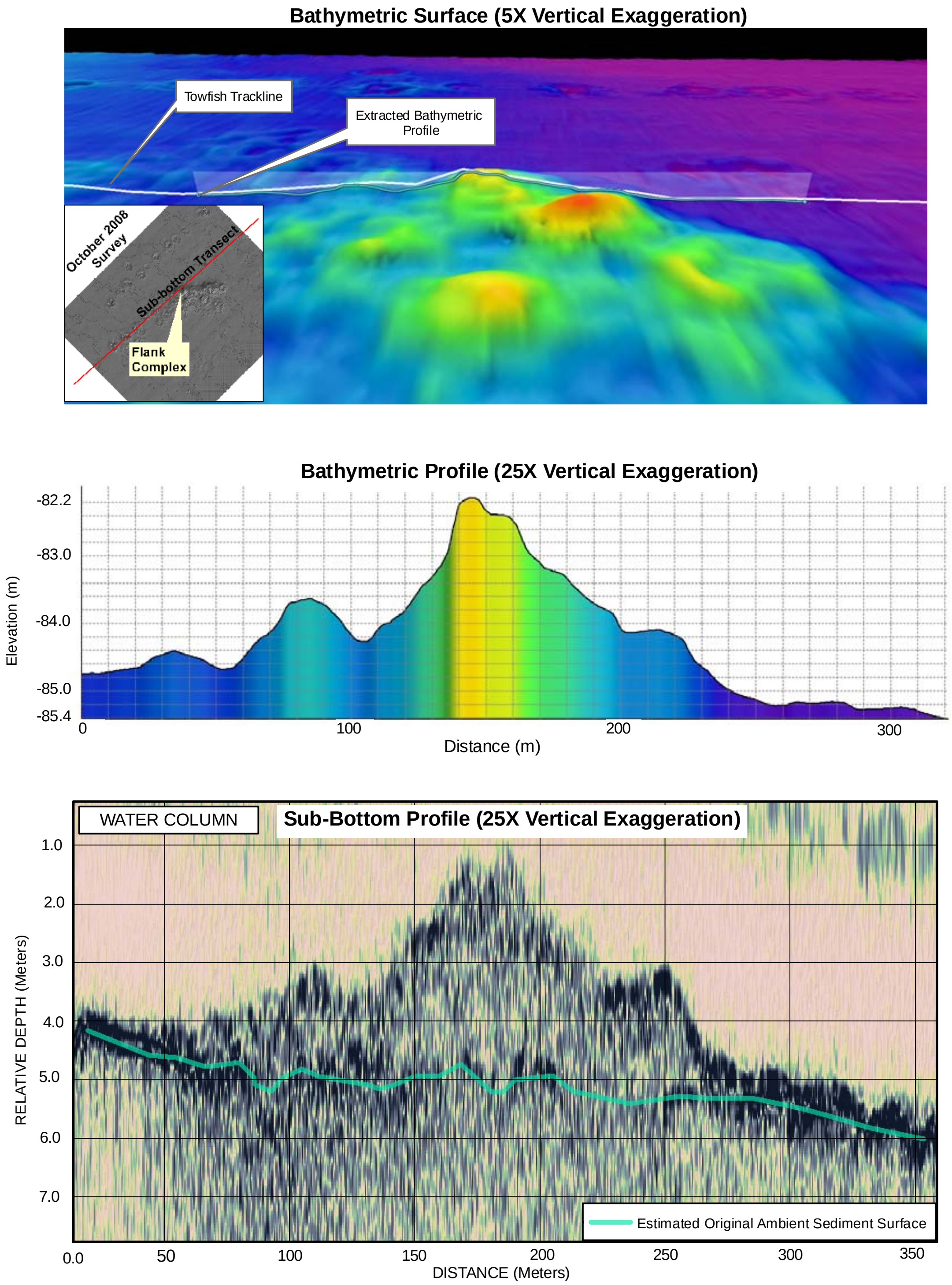

Figure 5-14: 2008 bathymetry and sub-bottom profile of the flank complex at the intersection of Line 1 and Lines 2-6

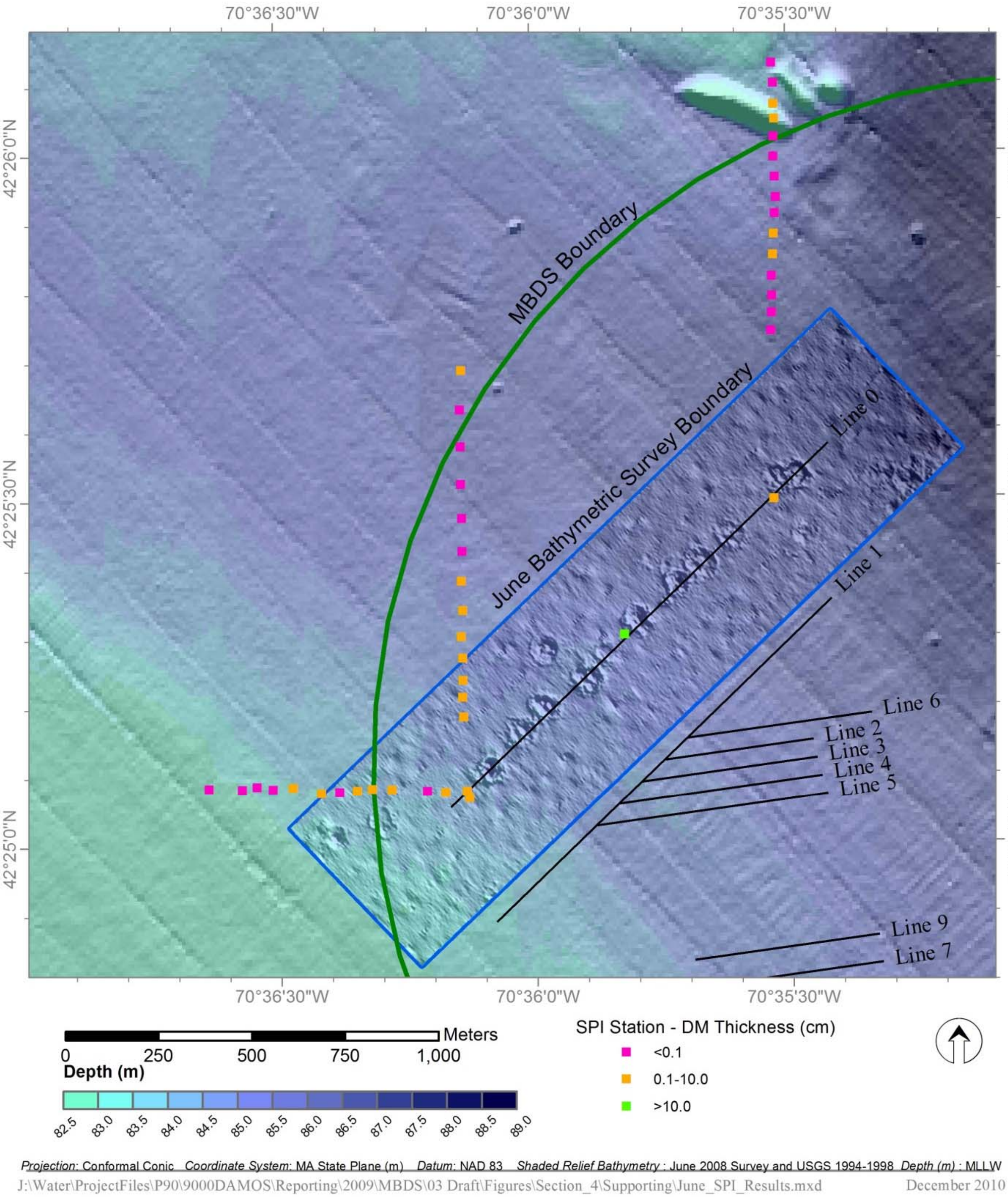

Figure 5-15: June 2008 SPI locations and measured thickness of dredged material (DM) following completion of single placement events along Line 0

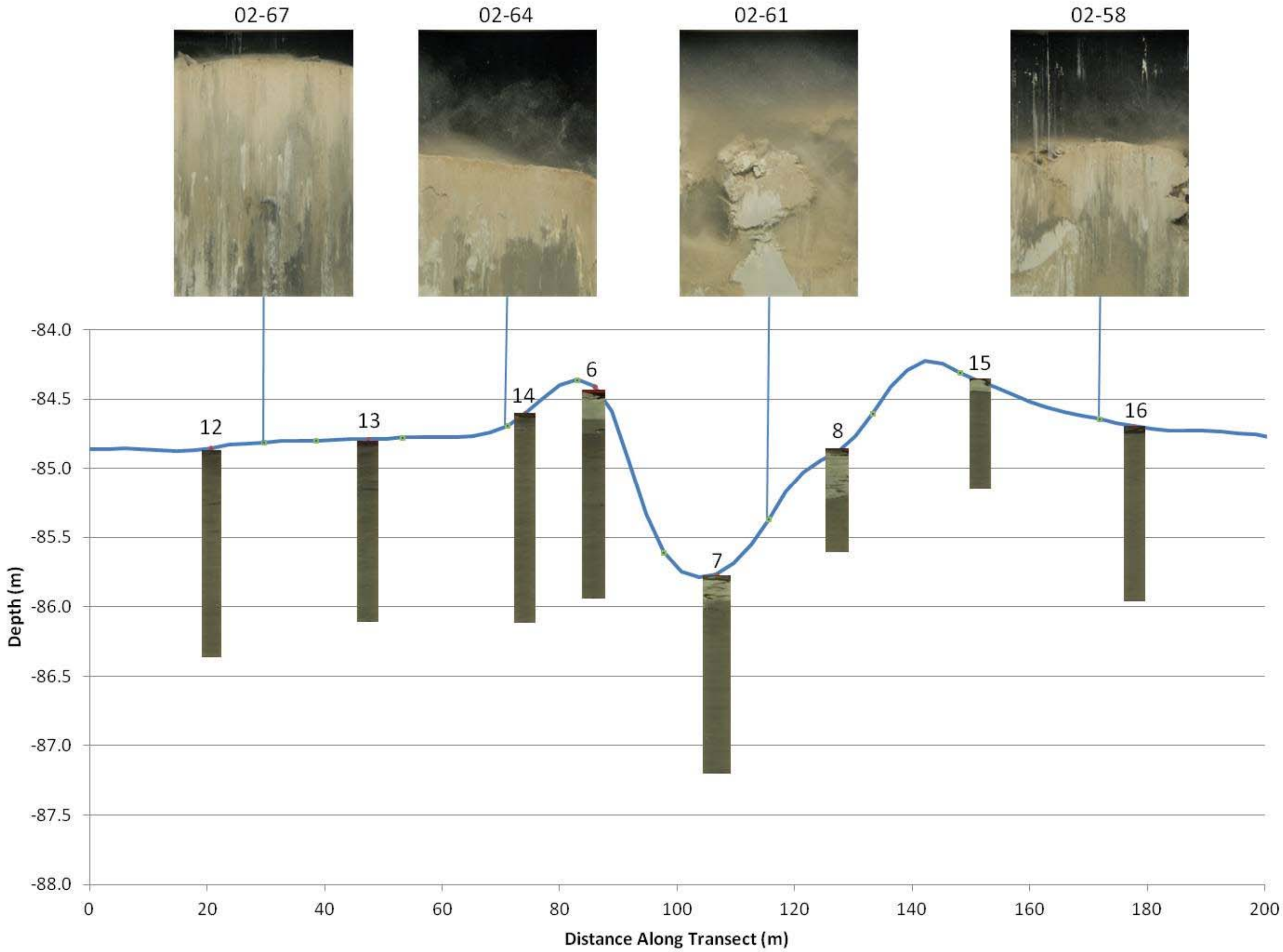

Figure 5-16: Transect through crater 1 on Line 0 showing bathymetry, core photos, and sediment profile images

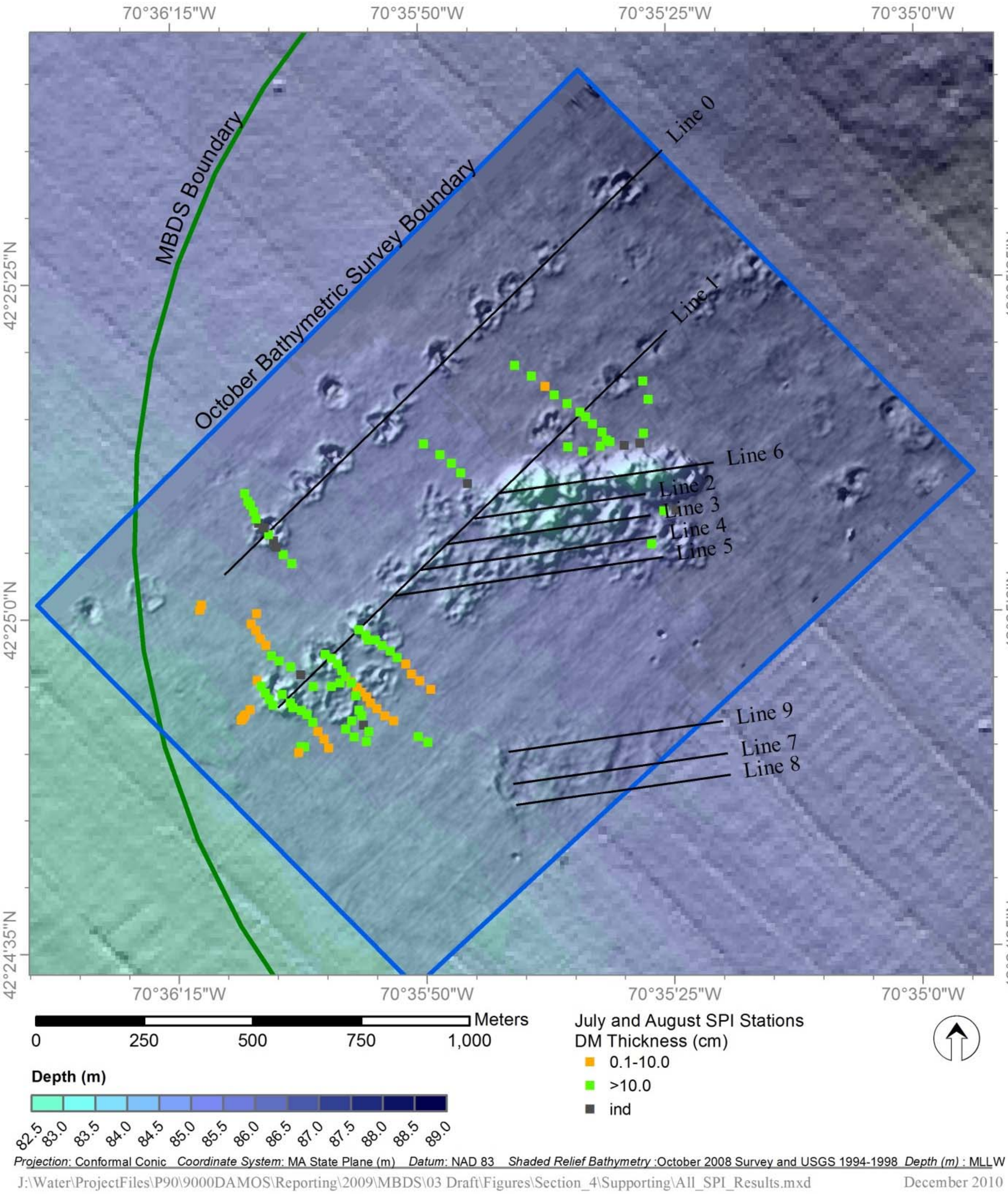

Figure 5-17: July and August 2008 SPI locations and measured thickness of dredged material (DM) following completion of placement at the RDA

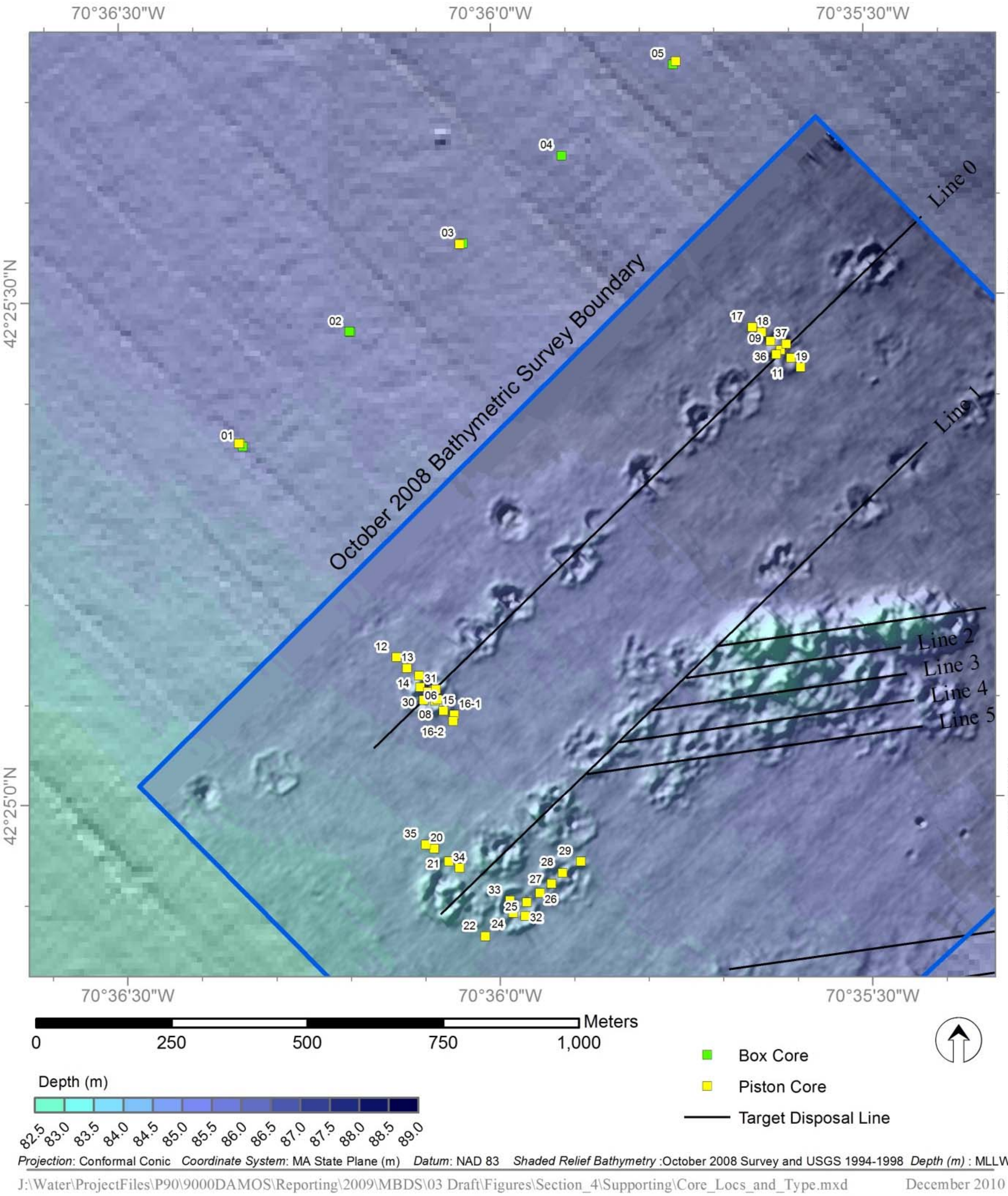

Figure 5-18: Locations and types of sediment cores collected in July 2009

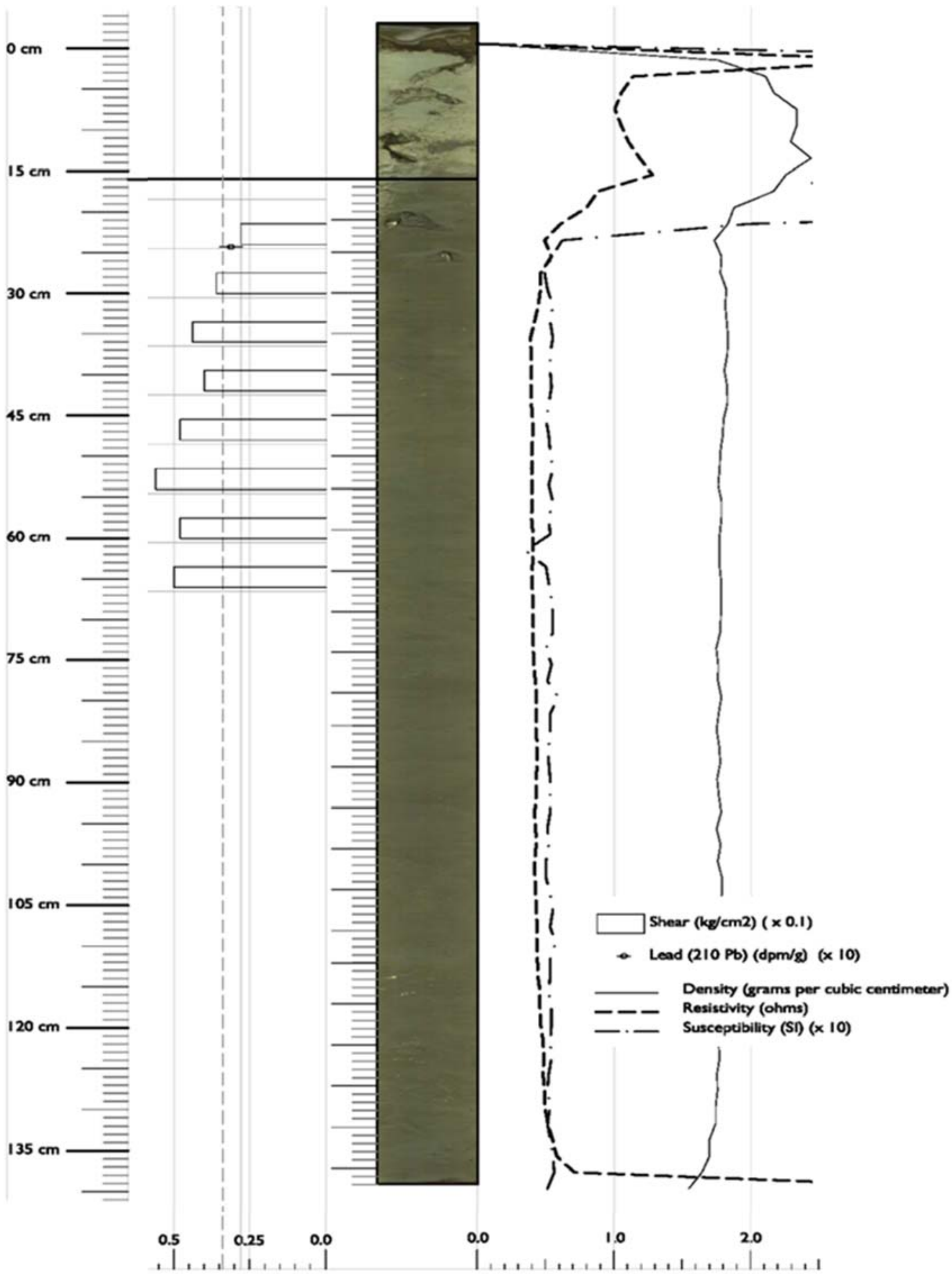

Figure 5-19: Core photo and plot of lab measured data for core 7-1 collected July 2009 (portions of lab plots cropped to maximize resolution of core photo)

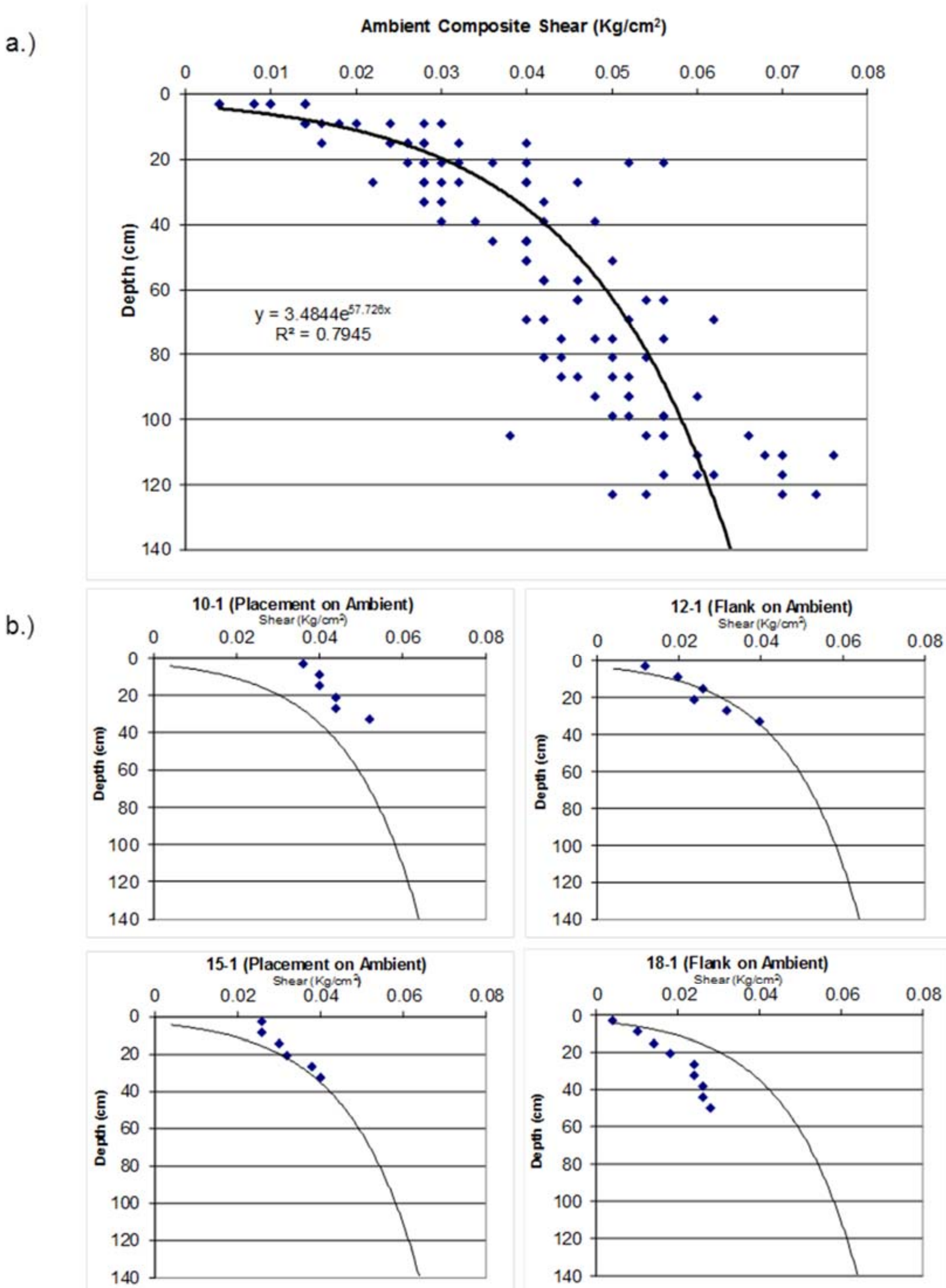

Figure 5-20: Shear strength (Kg/cm^2) plots for a) all ambient cores and b) representative individual cores with the ambient trend line for comparison

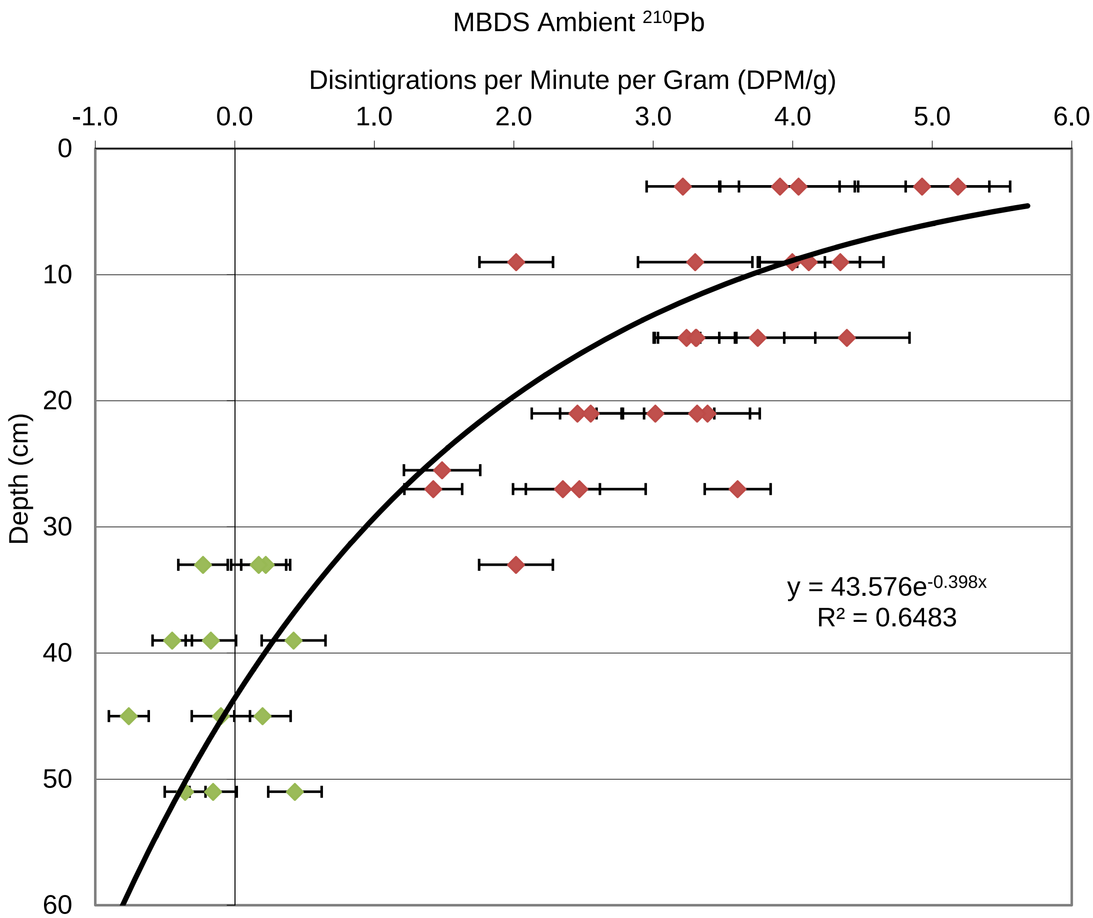

Figure 5-21: ^{210}Pb plots for ambient sediment cores (box cores shown in red, piston cores shown in green)

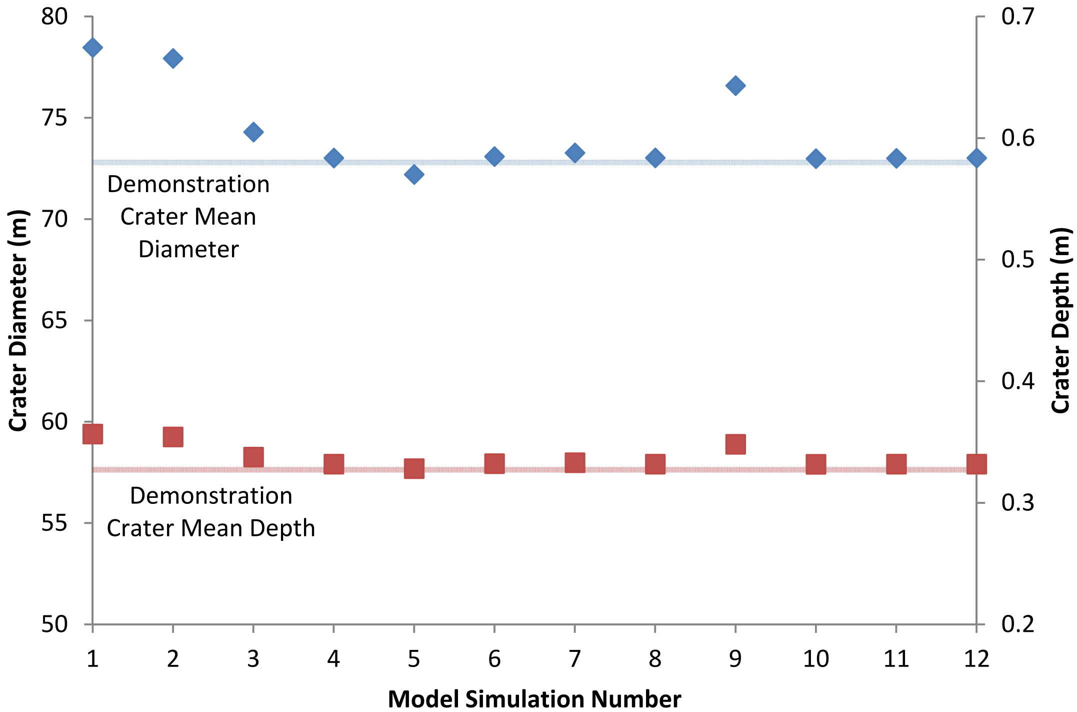

Figure 5-22: Model predicted crater dimensions from impacts of sediment clouds during typical placement scenarios at the IWS compared to the mean crater dimensions measured during the demonstration project (crater diameter data shown in blue, crater depth data shown in red).

Table 5-1
Data Matrix Summary

Study Question	Monitoring Tool	Data Use to Address Question
Can we place material with reasonable accuracy (within 30 m of a disposal transect and within 100 m of a specific point on that transect)?	Electronic barge tracking	Records position of barge when sediment is released. This can then be mapped relative to the target position and where material lands on the seafloor.
	Bathymetry	Using pre- and post-placement surveys the locations of sediment deposits can be determined based on evidence of bottom features (craters). The combination of target, placement position, and crater position for individual placement events can be used to assess the accuracy that can be achieved during normal operations.
How deep and wide are impact craters?	Bathymetry	Crater size, depth, and apron thickness measures.
	Sub-bottom acoustics	Crater size, depth, and apron thickness measures.
	Acoustic backscatter	Identifies extent of material spread on the bottom around the impact point and also zones of material type (clump distribution, smooth apron).
	Sediment cores	Taken in transects across craters and apron areas to assess change relative to baseline samples. Multiple measurements, itemized below, are used in combination to interpret layering.
	Visual description	Detect and measure visually distinctive layers and mixing. The Boston Harbor material was visually different than in-place sediment.
	Acoustic impedance	Detect distinctive materials and sedimentary patterns. Boston Harbor material had much higher acoustic impedance than in-place sediment.

Table 5-1
Data Matrix Summary

Study Question	Monitoring Tool	Data Use to Address Question
How deep and wide are impact craters? (continued)	^{210}Pb	Detect distinctive materials and sedimentary patterns. Ambient sediment exhibits a predictable decrease of ^{210}Pb with increasing sediment depth. Truncation of the pattern can be used to assess the depth to which the in-place sediment was disturbed.
	Density	Detect distinctive materials and sedimentary patterns. Ambient sediment exhibits a generalized pattern with increasing sediment depth. Truncation of the pattern can be used to assess the thickness of sediment overlying ambient.
	Grain size	Distinguishes deposits of native sediment (silt) and dredged material (clay).
	SPI camera	Identify undisturbed bottom areas around the crater and define the extent of the apron.
	Plan view camera	Identify bottom characteristics such as bottom clumps, smooth apron, and ambient bottom.
Can we effectively build up a lateral apron to protect the underlying sediment?	Bathymetry	Measure thickness of apron. Evaluated relative to the volume and approach used to place the sediment.
	Sub-bottom acoustics	Measure apron thickness over in-place sediments.
	SPI camera	Measure apron extent and thickness until it exceeds about 20 cm.
	Sediment cores	Measure apron thickness over in-place sediments with respect to grain size and ^{210}Pb profiles.

Table 5-1
Data Matrix Summary

Study Question	Monitoring Tool	Data Use to Address Question
Does this lateral apron effectively isolate the underlying sediment?	Bathymetry	Measure crater size and depth. Compare to events on ambient.
	Sub-bottom acoustics	Measure crater size, depth, and disturbance of ambient bottom in comparison to events directly placed on ambient.
	Sediment cores	Used in same manner as for second question and in comparison to those results.

Table 5-2
Target and Impact Distances for Disposal Lines 0 and 1

Target Point (Disposal Line - Crater)	Volume Placed* (m^3)	Impact Footprint Diameter (estimate, m)	Crater Depth** (estimate, m)	Estimated Bin Center to Impact Center Offset (estimate, m)
0-1	4300	85	1.1	68
0-2	4100	70	0.1	62
0-3	4200	83	0.3	43
0-4	4200	92	0.1	62
0-5	4400	59	0.1	92
0-6	4200	70	0.9	31
0-7	4200	66	0.2	68
0-8	4400	68	0.2	25
0-9	4300	81	0.2	40
0-10	3800	52	0.0	101
0-11	4000	75	0.4	62
Crater A	4300	65	0.0	68
Crater B	4300	76	+0.1	60

* As reported by the dredging contractor
**Calculated by determining the difference between the baseline bathymetric depth (2007) and the final bathymetric depth of the crater floor (October 2008)

Table 5-3
Summary of Sediment Cores Collected at RDA

Core ID	Type	Disposal Type	Penetration (m)	Recovery (m)	Latitude (N)	Longitude (W)
01-5	Box core	Ambient		0.3	42° 25.355'	70° 36.339'
02-1	Box core	Ambient		0.3	42° 25.468'	70° 36.192'
02-5	Box core	Ambient		0.3	42° 25.469'	70° 36.193'
03-2	Box core	Ambient		0.3	42° 25.555'	70° 36.040'
04-1	Box core	Ambient		0.3	42° 25.642'	70° 35.906'
05-2	Box core	Ambient		0.3	42° 25.731'	70° 35.755'
01-3	Piston core	Ambient	2.3	1.3	42° 25.359'	70° 36.343'
01-4	Piston core	Ambient	2.1	1.5	42° 25.359'	70° 36.344'
03-1	Piston core	Ambient	2.4	1.5	42° 25.555'	70° 36.044'
05-1	Piston core	Ambient	2.1	1.6	42° 25.734'	70° 35.752'
06-1	Piston core	Single disposal on ambient	1.8	1.5	42° 25.114'	70° 36.104'
07-1	Piston core	Single disposal on ambient	1.8	1.4	42° 25.110'	70° 36.093'
08-1	Piston core	Single disposal on ambient	1.8	0.8	42° 25.101'	70° 36.084'
08-2	Piston core	Single disposal on ambient	2.1	0.8	42° 25.102'	70° 36.081'
09-1	Piston core	Single disposal on ambient	2.1	1.3	42° 25.455'	70° 35.628'
10-1	Piston core	Single disposal on ambient	2.3	1.1	42° 25.446'	70° 35.615'
11-1	Piston core	Single disposal on ambient	2.4	1.6	42° 25.438'	70° 35.602'
12-1	Piston core	Flank on ambient	2.4	1.5	42° 25.144'	70° 36.135'
13-1	Piston core	Flank on ambient	2.1	1.6	42° 25.134'	70° 36.121'
14-1	Piston core	Flank on ambient	2.1	1.5	42° 25.125'	70° 36.105'
15-1	Piston core	Flank on ambient	2.1	0.8	42° 25.090'	70° 36.073'
16-1	Piston core	Flank on ambient	2.1	1.3	42° 25.086'	70° 36.058'
16-2	Piston core	Flank on ambient	2.1	1.1	42° 25.080'	70° 36.060'
17-1	Piston core	Flank on ambient	2.1	1.5	42° 25.469'	70° 35.652'
18-1	Piston core	Flank on ambient	2.1	1.3	42° 25.464'	70° 35.641'
19-1	Piston core	Flank on ambient	2.4	1.4	42° 25.428'	70° 35.588'
20-1	Piston core	Multiple flank on ambient	2.3	1.5	42° 24.953'	70° 36.087'
21-1	Piston core	Multiple flank on ambient	2.3	1.4	42° 24.940'	70° 36.068'
22-1	Piston core	Single disposal on flank	2.1	1.6	42° 24.865'	70° 36.020'
23-1	Piston core	Single disposal on flank	2.1	1.4	42° 24.877'	70° 36.000'
24-1	Piston core	Single disposal on flank	2.1	1.5	42° 24.888'	70° 35.981'
25-1	Piston core	Single disposal on flank	2.4	1.6	42° 24.899'	70° 35.963'
26-1	Piston core	Single disposal on flank	2.4	1.6	42° 24.908'	70° 35.946'
27-1	Piston core	Single disposal on flank	2.4	1.5	42° 24.917'	70° 35.931'
28-1	Piston core	Single disposal on flank	2.4	1.5	42° 24.927'	70° 35.915'
29-1	Piston core	Single disposal on flank	2.6	1.6	42° 24.939'	70° 35.891'
30-1	Piston core	Single disposal on ambient	2.1	1.5	42° 25.101'	70° 36.099'
31-1	Piston core	Single disposal on ambient	2.1	1.1	42° 25.112'	70° 36.083'
32-1	Piston core	Single disposal on ambient	2.3	1.6	42° 24.885'	70° 35.965'
33-1	Piston core	Single disposal on ambient	2.1	1.6	42° 24.901'	70° 35.986'
34-1	Piston core	Single disposal on ambient	2.3	1.6	42° 24.934'	70° 36.053'
35-1	Piston core	Flank on ambient	2.1	1.6	42° 24.957'	70° 36.098'
36-1	Piston core	Single disposal on ambient	2.1	0.9	42° 25.442'	70° 35.621'
37-1	Piston core	Single disposal on ambient	2.4	1.5	42° 25.452'	70° 35.607'

6.0 SIDE-SCAN SONAR IMAGING OF THE IWS

In a parallel effort to characterize the IWS, EPA scientists aboard the Ocean Survey Vessel (OSV) Bold conducted a side-scan sonar survey in the vicinity of MBDS and the IWS in July of 2006. The purpose of this survey was to determine if the then newly acquired Klein 3000 dual frequency side-scan sonar could identify and locate historically disposed waste containers and other targets identified in previous side-scan and video surveys discussed in Section 2.2 of this report (Wiley et al., 1992, NOAA, 1996). Processing of the 2006 data enabled the EPA to identify and rank three priority areas for restoration based on the density of targets presumed to be waste containers. A similar survey was conducted aboard the OSV Bold in June of 2010 to reconfirm targets from the previous surveys and to better define the spatial extent of waste containers to the north and west in order to identify a reasonable starting point for future restoration efforts.

6.1 Methods

6.1.1 2006 Side-Scan Sonar Data Collection and Processing

Three sets of side-scan sonar data were collected by the OSV Bold in the vicinity of MBDS and the IWS between 15 and 18 July 2006 (Figure 6-1) using the Klein 3000 system operating at 100 and 500 kHz frequencies. Survey transects were planned using Klein SonarPro software and transferred to the Bold's onboard Nobeltec Navigation system for use in the field. Positioning was achieved using the ship's Raytheon Differential GPS with an accuracy of +/-5 m. All survey data was viewed in real time for preliminary target acquisition as well as being recorded to a hard drive in .xtf format by SonarPro.

The first side-scan data set (MBDS N-S) consisted of 14 transects in a north-south orientation covering the northeast portion of MBDS (Figure 6-1). This survey was designed with a 1210 m transect length, 100 m line spacing, and a sonar range of 150 m. Due to mechanical problems with the tow fish cable only 7 transects were completed (odd numbered transects in the south direction only).

The second data set (IWS N-S) consisted of 15 transects in a north-south orientation covering the IWS and the northwest portion of MBDS in areas where waste containers had previously been observed (Figure 6-1). Coordinates for possible targets were based on IWS field investigations conducted in 1992 (NOAA, 1996). This survey was designed with a 1852 m transect length, 200 m line spacing, and a sonar range of 150 m.

The third data set (IWS E-W) consisted of 11 transects in an east-west orientation covering a portion of the IWS already surveyed by the second data set, but at a slower speed and lower altitude in order to obtain a better resolution for target identification (Figure 6-1). This survey was designed with a 2240 m transect line length, 125 meter line spacing, and a sonar range of 75 m. Currents were strong during this survey, and data acquisition was not accurate in the eastbound transects because the heading of the tow fish and the ship were not concurrent. After six transects, only westbound transects were conducted, and the transect numbers were re-set.

The 500 kHz dataset from each side-scan dataset was imported and processed separately using Chesapeake Technology SonarWiz.MAP software. Processing included the merging of .xtf files from each individual trackline, refinement of towfish layback distances, navigation track smoothing and filtering of any errant GPS points, digitizing of the first signal return to remove the water column portion of the sonar record, and adjustments for signal attenuation with distance using Time Varied Gain (TVG) corrections. The processed tracklines were then combined into a high resolution mosaic for each dataset.

The accuracy of target data was assessed prior to track smoothing. Most of the positional error observed was attributed to long cable lengths and the layback algorithm used by Sonar Pro to calculate the position of the towfish. The accuracy of towfish layback was assessed by comparing the positions of recognizable features imaged on adjacent lines. Layback was adjusted until these features were in agreement within the dataset mosaic. Pre-adjustment error was determined to be as much as 40 m. Post adjustment accuracy was assessed by comparing points on a shipwreck in the IWS N-S transects with the IWS E-W. Post adjustment accuracy was determined to be approximately 25 m, but the range and resolution differences between the datasets did not allow for accurate comparison of a large number of smaller targets.

Individual targets from the IWS E-W survey were identified in SonarWiz and classified into one of ten categories based on size and shape, metallic characteristics, and environmental setting. Each target was logged into an electronic database which included its sonar image, position, measurements, classification, and probability of being a waste container. The range and resolution of the IWS N-S and MBDS N-S data sets did not allow for the level of classification described above, but they were reviewed in order to identify and log any targets that were considered to be drum like. The resolution of the IWS E-W survey allowed for positive identification of objects approximately 0.5 m or larger on the seafloor.

6.1.2 2010 Side-Scan Sonar Data Collection and Processing

Another side-scan sonar survey was conducted by the EPA aboard the OSV Bold in the vicinity of MBDS and the IWS between 24 and 25 June 2010 (Figure 6-2). The primary objectives of this effort were to reconfirm probable waste containers identified during the analysis of the 2006 survey data, to define the northern and western extent of probable waste containers, and to reconfirm or identify the locations of other features to be considered during the design of the proposed restoration effort. The equipment and methodology used for data collection were identical to the 2006 effort. The survey consisted of 28 transects in a north-south orientation covering the IWS and northwest portion of MBDS. The survey was designed with a 3125 m transect length, 100 m line spacing, and a sonar range of 75 m. Approximately 95% of the survey area was covered successfully, but a portion of the data collected from transects 46, 48, and 52 was rendered unusable due to entanglement of the towfish with fishing gear.

The 500 kHz data recorded in SonarPro was imported to Chesapeake Technology SonarWIZ 5 for processing and analysis. Processing included the merging of .xtf files for each individual trackline, refinement of towfish layback distances, digitizing of the first signal return to remove the water column portion of the sonar record, and adjustments for signal attenuation with distance using TVG corrections. The processed tracklines were then combined into a high resolution mosaic.

The accuracy of towfish layback was assessed by comparing the positions of recognizable features imaged on adjacent lines and by comparison with multibeam bathymetric data (where available). Layback adjustments of 9 to 40 m were applied to 9 of the 28 transects until compared features were in agreement. With few exceptions, layback accuracy was determined to be within 5 m.

A 2.2 x 0.7 kilometer area in the northwestern portion of the survey area was examined in detail in order to identify and classify targets according to the survey objectives. Targets were logged into an electronic database which included a sonar image, position, measurements, classification, and probability of being a waste container. In addition, the 2010 side-scan sonar data was also examined within EPA Priority Area 2 to identify possible anthropogenic targets. These targets were not classified to the same extent as the northwestern analysis area but included possible waste containers, debris, and fishing gear. The resolution of the 2010 survey allowed for positive identification of objects approximately 0.5 m or larger on the seafloor.

6.2 Results

Analysis of the 2006 and 2010 IWS transects resulted in the identification and classification of 1034 and 716 targets respectively into one of sixteen categories (Tables 6-1 and 6-2). An additional 991 high or moderate certainty anthropogenic targets were also identified in the Priority Area 2 portion of the 2010 IWS transects. The overall number of targets observed in the dataset was too large to enumerate so a focus was placed on drum-like objects, metallic debris, and encasement targets.

The dominant feature observed during target analysis was a high density of drum-like targets and metallic debris focused in the portions of the survey area that fell within the historic boundaries of the IWS. This cluster of drum related targets most likely continues further north as suggested by the large number of unidentified point targets found in the IWS N-S sonar records, but this could not be confirmed due to the range and resolution of the dataset. Furthermore, the actual number of drum-like targets within the IWS E-W dataset is most likely higher than reported due to poor reflectance from drums in more advanced states of decomposition and low resolution in the area directly under the towfish. It should be noted that the analysis of sonar data and visual confirmation of targets from the 1991 survey suggests that almost all targets outside areas of dredged material and glacial deposits were drum related.

Analysis of the IWS E-W dataset also suggested two focused areas of possible encasement targets within the southwest portion of the survey area. A small number of potential individual encasement targets were observed scattered outside of these areas.

Other identified man made features of interest included multiple shipwrecks, derelict fishing gear, and several scattered clusters of dredged material. General areas with dredged material or glacial deposits were identified and delineated, but individual geologic features were classified only when found outside these areas or in close proximity to drum-like targets. Areas delineated as dredged material occurred within the boundary of the Interim Massachusetts Bay/Foul Area Disposal Site (FADS).

Mapping of the spatial distribution of probable waste containers within the survey area allowed the EPA to designate and rank three priority areas for restoration (Figure 6-3) based on target density. Priority Area 1 consists of the area with the highest density of drum-like objects and probable concrete encasement targets in the west and central portions of the IWS E-W survey area. Priority Area 2 covers of the area to the north where numerous unconfirmed but likely drum-like targets were identified in the IWS N-S dataset. Priority Area 3 consists of the eastern portion of the IWS E-W survey where barrel density and distribution diminishes significantly with distance from Priority Area 1.

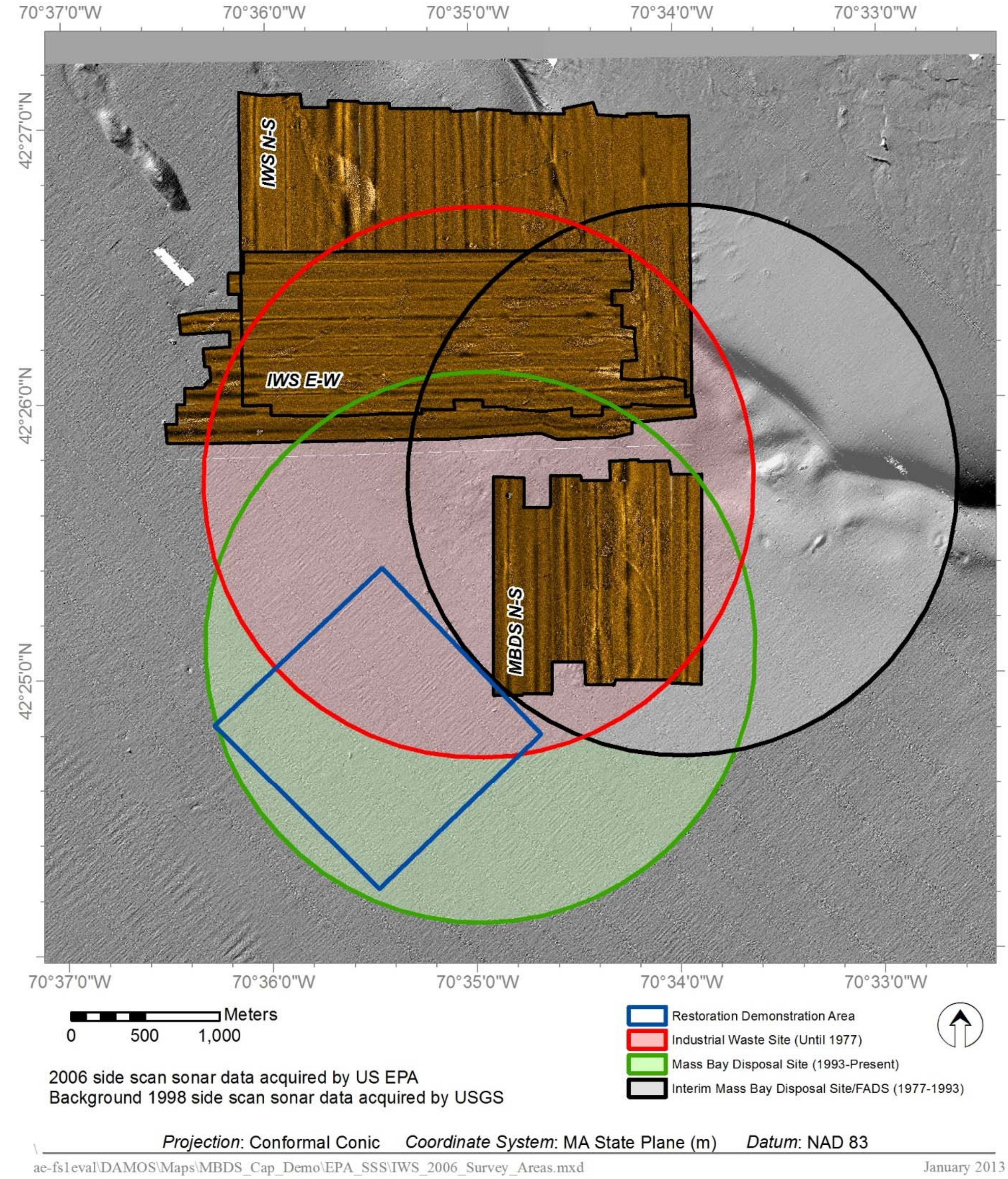

Figure 6-1: Side-scan sonar mosaic from 2006 EPA survey

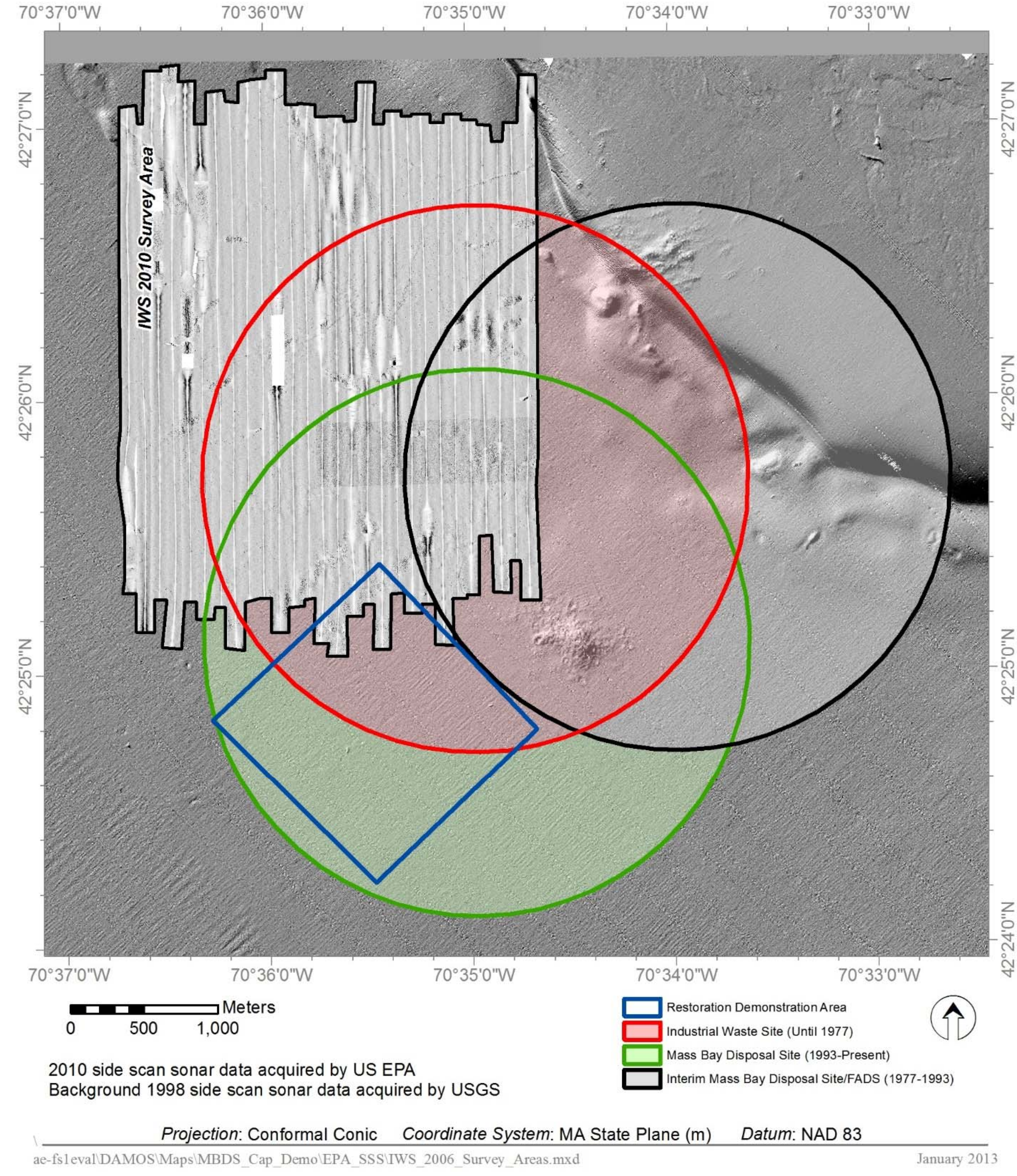

Figure 6-2: Side-scan sonar mosaic from 2010 EPA survey

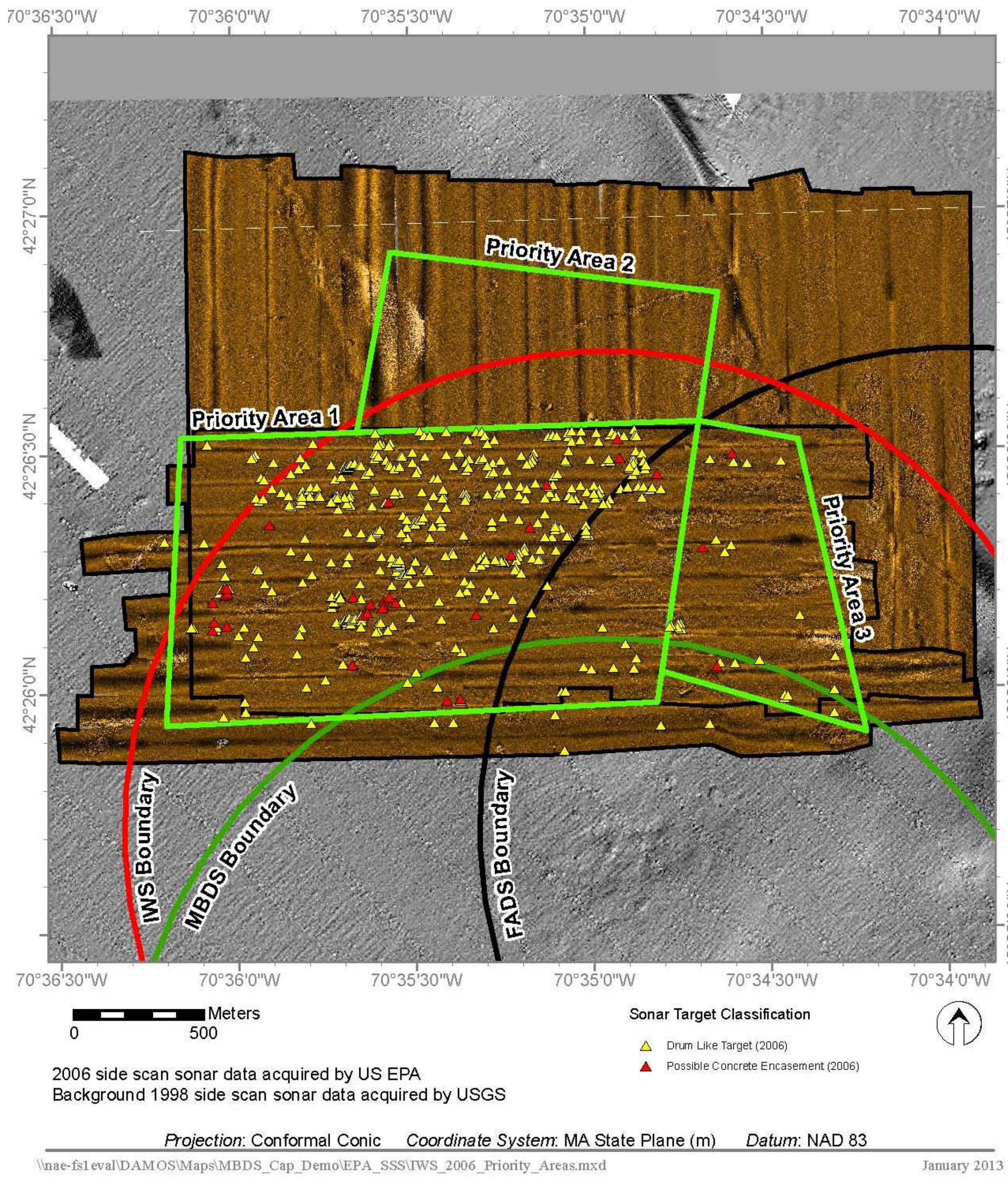

Figure 6-3: Targets identified in Priority Area 1 and Priority Area 3 from the 2006 EPA side-scan sonar survey

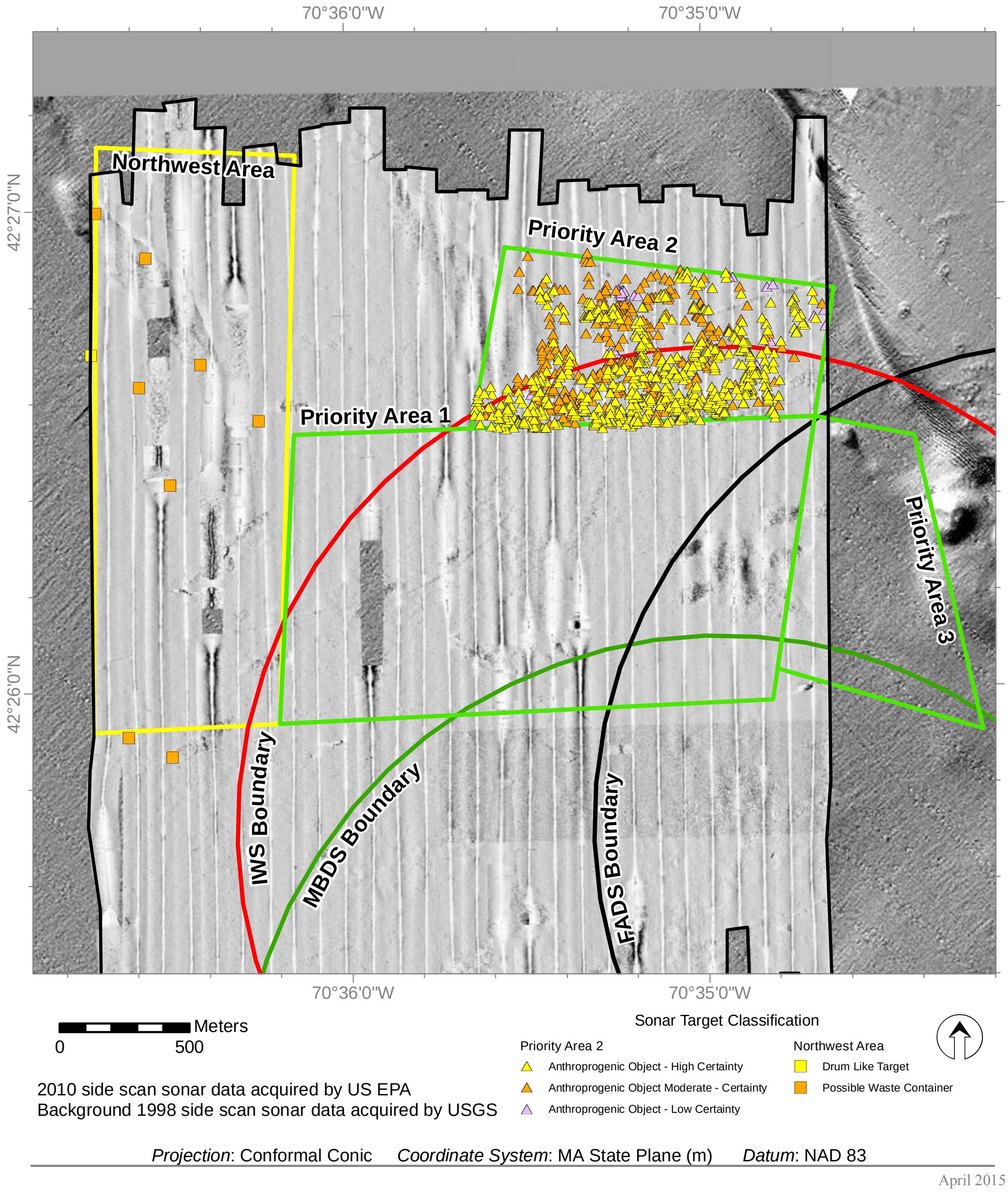

Figure 6-4: Targets identified in Priority Area 2 and the northwestern analysis area from the 2010 EPA side-scan sonar survey

Table 6-1

Classifcation of Side-Scan Sonar Contacts (EPA 2006)

Contact Category	Count	Description
Drum Like Target	481	Targets with dimensions roughly equivalent to a drum (Approximately 0.9m x 0.6m), a rectangular shadow, and metallic characteristics such as ringing and flaring.
Metallic Debris	325	Targets which exhibit metal characteristics such as ringing or flaring but did not meet the size and shape criteria of a Drum Like Target.
Unknown Material	101	Targets which could not be identified as a Drum Like or Dredge Material/Rocks/Glacial Deposits but did appear to have shape or size characteristics close to drums.
Non-Drum Like Man Made Debris	39	Targets that were apparently man made but clearly not drum like or associated with drums such as the metallic debris
Possible Concrete Encasements	35	Targets having dimensions larger than a drum with a regular rectangular shape.
Rock- Boulder	26	Rocks and boulders only those in proximity to drum like targets or outside the obvious dredge/rock disposal locations
Dredge Material / Glacial Deposit	9	All types of dredge, and rock material deposited in the survey area. Additionally some of the rock material seen on the side-scan may also be naturally occurring glacial deposits.
Lobster Trap	7	Targets which exhibited clean crisp rectangular signatures within the proper size constraints and with fishing gear characteristics.
Shipwreck	6	Sunken vessels were designated as shipwrecks.
Fish	4	Targets which exhibited the classic characteristics of fish schools.
Total No. Contacts	**1034**	

Table 6-2

Classifcation of Side-Scan Sonar Contacts (EPA 2010)

Contact Category	Count	Description
Object (anthropogenic)	351	Sonar feature with non-random structure or outlying location which indicates man-made origin. Classification was used when man-made features could not be added to a more descriptive category.
Possible Buried Object	168	Classification was used when man-made features could not be added to a more descriptive category and no sonar "shadow" was visible.
Lobster Trap (single)	129	Object with dimensions and characteristics consistent with commercial lobster fishing gear.
Lobster Trap(s) (clustered)	14	Cluster of objects with dimensions and characteristics consistent with commercial lobster fishing gear.
Wreckage (ship)	11	Clearly defined remnants of a sunken vessel.
Waste Container (possible)	8	Object of anthropogenic origin consistent with container descriptions and unlikely to be fishing gear.
Fishing Scour	7	Narrow linear depression of the seafloor associated with trawl doors or dragging of lobster traps.
Construction Debris	6	Mix of irregular and block-like features, signals and apparent relief consistent with disposed material.
Wreckage (unknown)	6	Objects which appear to be associated with a sunken vessel.
Pipeline	5	Linear raised feature. Compared with known structures in CR's database for identification.
Structure (unknown)	4	Feature associated with pipeline or other infrastructure which cannot be further characterized.
Disposed Material Cluster	2	Generally irregular features with signals and apparent relief consistent with coarse disposed material.
Suction Anchor	2	Suction anchors for the Neptune Pipeline
Dredge Material	1	Features with signals consistent with disposed dredge material.
Drum/Barrel	1	Feature with dimensions/signal consistent with a drum. Note that this classification is highly uncertain due to the similarity between the dimensions of commercial lobster gear and weathered containers.
Tire	1	Feature with a low-amplitude signal, dimensions and shape consistent with a tire.
Total No. Contacts	**716**	

7.0 RESTORATION DEMONSTRATION DISCUSSION

Interpretation of these study results benefits from having an understanding of the dimensional scales of the site and the equipment used to conduct the demonstration project. Although the common perception is that the water in Massachusetts Bay is very deep, when placed in the proper perspective to the construction equipment used, it becomes evident that water depth is a relatively minor factor as the time from barge release to bottom encounter is brief.

The depth of water at the IWS is about 90 m, or about the height of a 30 story building. The barges used to place the sediment have a total length of about 75 m and have a draft, when fully loaded, of about 4 m (Figure 5-10). When the barges open, the sediment falls through an elongated opening about 70 meters long. Only a few seconds pass between the release of the sediment from the barge and arrival of the material at the bottom (Johnson and Schroeder 1993). This places important context on the interpretation of the demonstration results, particularly in relation to the accurate placement of material on the seafloor as discussed in the next section.

7.1 Ability to Direct Placement of Material

This project successfully demonstrated the ability to accurately direct placement of dredged material at MBDS without altering the schedule, or incurring additional costs, to an opportunistically used dredging project. The 2008 Boston Harbor dredging project generated approximately 750,000 m^3 of material for open water placement at MBDS. Approximately 380,000 m^3 of this material consisted mostly of Boston Blue Clay and glacial till from the excavation of two confined aquatic disposal (CAD) cells in the harbor and was utilized for the demonstration project. This material is comparable to the expected sediments that will be generated from the upcoming Boston Harbor deepening project that would be available for full-scale restoration of the IWS.

As presented in Section 5.3, tug captains achieved a high degree of accuracy throughout disposal operations and averaged less than 62 m between target coordinates and disposal crater points (Table 5-2 and Figure 5-9). This is particularly impressive given that the target offset was often within the scale of the barge hopper itself (Figure 5-10). It is clear from the data collected through this demonstration project that a simple operational plan of tug approach lines and target disposal points can be utilized at MBDS to accurately place material on the seafloor in a strategic manner to implement a sequenced disposal approach to restore the IWS.

7.2 Distribution and Thickness of Dredged Material

The demonstration project documented and analyzed the distribution of dredged material from placement activities in the Restoration Demonstration Area (RDA). Impact features showed characteristics that aligned well with the predictions of the conceptual model and previous studies presented in Section 3.

The placement of dredged material at the RDA with split-hulled barges created distinct crater formations on the seafloor (Figure 5-1). These features were characterized by circular rings of material around the impact point that ranged from 60–100 meters across. As predicted, the rings of dredged material formed a berm (evident in bathymetric and backscatter data as well as sediment-profile and plan-view imagery) that was thickest around the disposal point and tapered off to a thin apron several hundred meters away.

Dredged material thickness and lateral spread was dependent on the disposal volume; based on the number of barge loads placed at a single location. Individual disposal events of 4,000–4,500 m^3 along Line 0 created berm deposits 0.1–0.5 m thick over the original baseline surface. These craters exhibited comparatively sharp side slopes from the crater floor to the surrounding rim and berm deposits were irregular and uneven with large (>50 cm) blocks of clay visible in sediment-profile and plan-view imagery (Figure 7-1).

Placement of two to three barge loads of material at the targets along Line 1 yielded berm deposits 0.5–1.0 m thick within 50 meters of the impact point. The berm was more consistent than the individual placement berms observed on Line 0 and remained 0.3 m thick 150 m from the impact point (Figure 7-2). Placement of up to five barge loads at single targets along Lines 2–6 created berm formations up to 3.0 m thick (Figure 7-3). This establishes that a substantial berm of cover material can be developed through the sequential placement of multiple barge loads of Boston Blue Clay and glacial till at MBDS using conventional disposal equipment and methods.

7.3 Impact of Placement on Ambient Sediments

Multiple lines of evidence were analyzed to determine the extent of disturbance to in-place sediments from the disposal of dredged material at MBDS. The single disposal events along Line 0 displayed varying degrees of scour, compaction, and disturbance of the underlying seafloor sediments. Depth difference calculations from the baseline multibeam bathymetric survey in 2007 and the post-Line 0 disposal survey in June of 2008 revealed crater formations that penetrated the ambient sediment over one meter deep (Table 5-2). Analysis of sub-bottom profiles from these formations also showed substantial deflection of the original surface beneath the dredged material deposit; further suggesting that the ambient sediments were likely disturbed by the placement process (Figure 5-12).

Lack of sufficient penetration of the sediment-profile camera into the consolidated Boston Blue Clay deposits limited the use of SPI imagery to determine the extent of disturbance from demonstration area disposal events. At most SPI stations near impact features the dredged material deposits were deeper than the camera penetration (Figure 5-17).

The 2009 sediment coring survey focused on two disposal events along Line 0 (Figure 5-18). The most informative line of evidence to determine potential disturbance to underlying sediments was an analysis of grain size types within the cores. Samples from ambient cores were analyzed to determine the grain size characteristics of the seafloor sediments at MBDS. The minimum and maximum percent composition of clays, silts, and sands were calculated for all ambient samples to develop a range of "ambient-like" grain size signatures (Table 7-1). As would be expected, the ambient seafloor at MBDS exhibited relatively small variation in grain size types, with ranges of less than 12% for all categories (Table 7-1).

The resulting ranges were then compared to samples from the demonstration cores to identify core intervals with grain size characteristics that were outside of the ambient range. Non-ambient like grain sizes in the samples represented intervals with dredged material, or a mixture of dredged material and ambient material, in the cores and acted as a tracer to determine the depth of disturbance at disposal points.

Cores with non-ambient like grain size signatures below the visually identified dredged material horizon were plotted to highlight the spatial extent of sub-surface disturbance from disposal events at MBDS (Figure 7-4). Core transects were collected across two impact craters on Line 0 where disposals were placed directly on the ambient seafloor. A total of 11 of the 18 cores exhibited non-ambient like grain sizes below the defined dredged material layer at stations within the crater floors, along the rims, and into the flanks; indicating widespread disturbance and mixing of dredged material with in-place sediments. Some cores showed non-ambient like grain size signatures more than 40 cm deep into the ambient sediments. This suggests that direct placement of dredged material on the ambient seafloor has the potential to disturb the in-place sediments and waste containers at the IWS.

7.4 Impact of Placement on a Berm

To assess the ability of a berm to absorb and deflect some of the impact forces generated through the disposal process, two to three barge loads of material were placed at individual targets along Line 1 (Figure 7-2). This created a berm of material approximately 0.3 m thick up to 150 meters from the impact point. That berm was then targeted for the placement of individual barge loads of material approximately 115 m from the Line 1 impact points (Craters A and B in Figure 5-5).

The resulting bathymetric features of these craters exhibited certain differences from the disposals on ambient seafloor along Line 0. The overall depth of the craters over the berm was much shallower than the craters on Line 0. Crater A showed no depth change from the pre-disposal survey and Crater B showed an accumulation of 0.1 m of material; this is in contrast to up to 1.1 m of scour measured over the Line 0 craters (Table 5-2).

In addition to the size difference, Craters A and B also exhibited shallower profiles than the disposals on ambient seafloor, further supporting a transfer of downward energy in a lateral direction as predicted by the conceptual model. This successful transfer of energy is highlighted by the examining the bathymetric profiles of the baseline seafloor (2007), berm formation (July 2008), and post-disposal survey (October 2008) for Crater A (Figure 7-5). The two disposals on ambient sediment that formed Crater 1-2 clearly eroded the in-place sediments and formed a relatively steep crater with a wide berm. The single disposal placed on the berm formed a wider and shallower impact crater that did not erode the original ambient surface (Figure 7-5).

Applying the grain size comparison discussed in the previous section to the cores that were collected from Craters A and B further supports the ability of the berm to reduce disposal impact forces. None of the nine cores collected in a transect across the Crater A and Crater B floor, rim, and flank areas exhibited non-ambient like grain size signatures below the defined dredged material deposit (Figure 7-4). This suggests that there was no measurable mixing of dredged material with ambient sediments beneath the berm.

Based on these lines of evidence it is apparent that a fairly small (0.3 m) berm of Boston Blue Clay and glacial till can successfully absorb the impact forces from the disposal of a split-hulled barge load of dredged material at MBDS. The berm served to protect the underlying sediments from the disposal process, transferring the energy in a lateral direction, and limiting the disturbance to in-place sediments.

7.5 Scale Up to Restoration at the IWS

Building on the process outlined in the previous section, it would be possible to use the dredged material generated from the Boston Harbor deepening project to cover the waste containers and restore the IWS. Analyzing the complex berm formed from the multiple disposals along Lines 2–6 provides insight into possible full scale restoration scenarios. Approximately 272,000 m^3 of dredged material was placed along lines 50 meters apart to create the Line 2–6 formation. Depth difference analysis of the baseline (2007) and post-disposal (October 2008) multibeam surveys showed the formation to have a net volume of 143,000 m^3. The approximately 50% conservation of volume is due to several factors including material compaction, inaccurate barge volume estimates, entrained water from the dredging process, and the portion of a disposal load dispersed in the thin outer apron hundreds of meters from the impact point.

This conservation of volume can be applied to predict the net result from the disposal of Boston Blue Clay and glacial till by split-hull barges for the full scale restoration of the IWS. It is expected that the “loss” of material to the outer apron will be minimized as the disposal sequence progresses making the 50% expression of volume a conservative estimate to develop the full scale restoration design.

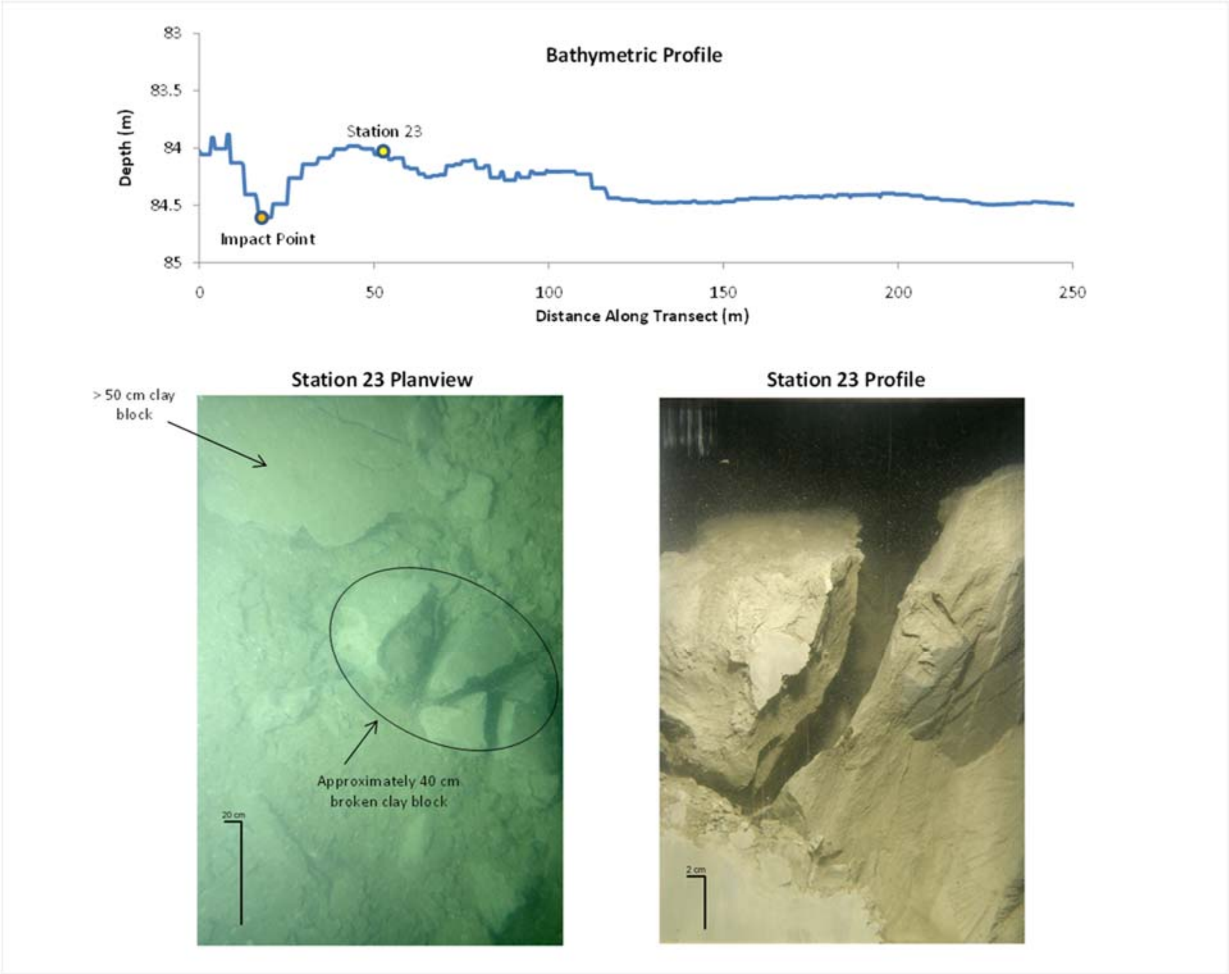

Figure 7-1: Bathymetric profile and sediment-profile and plan-view images of a single placement on ambient material (crater 1, Line 0)

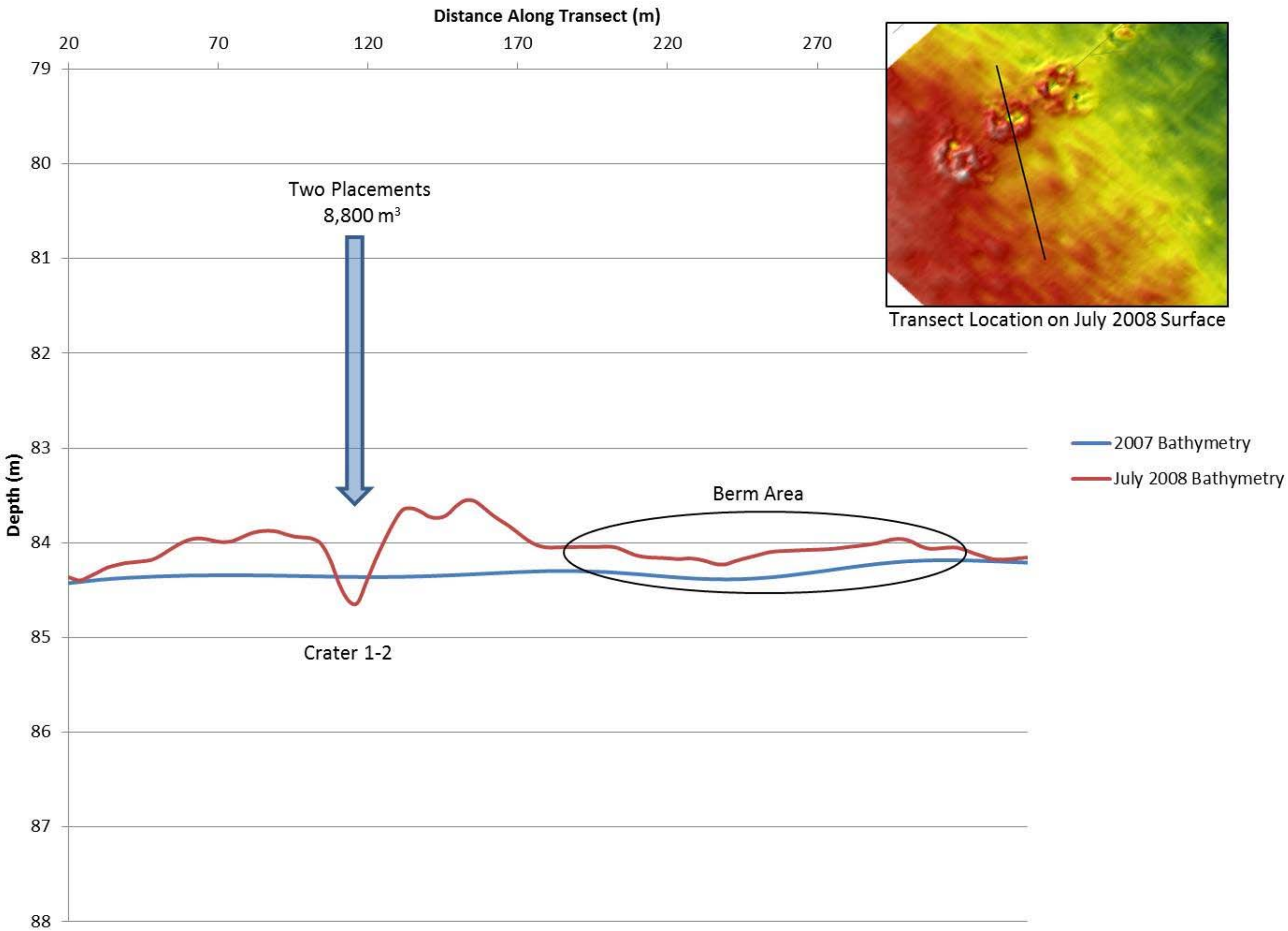

Figure 7-2: Bathymetric profile of a simple berm formation from two co-located placements on Line 1

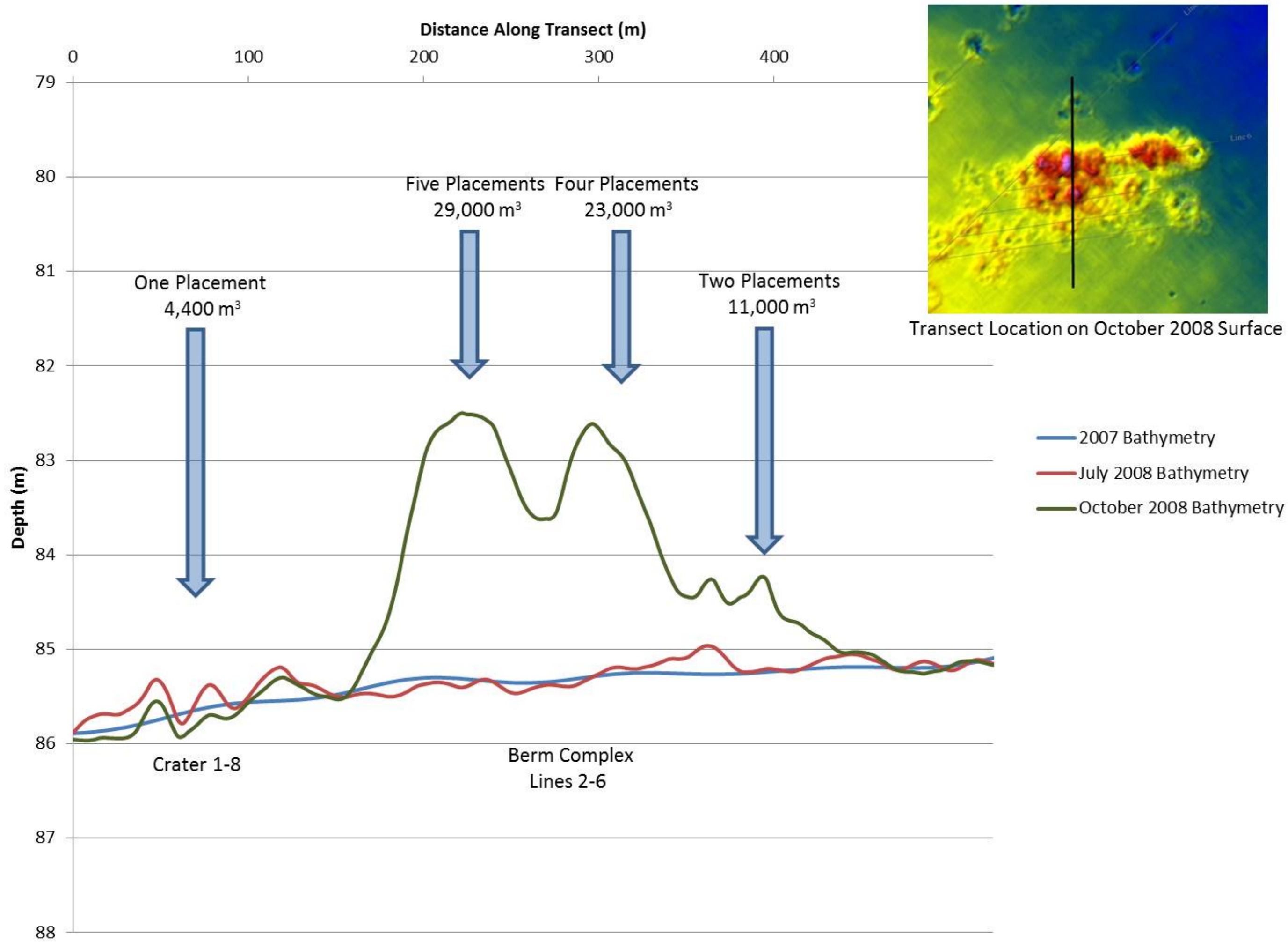

Figure 7-3: Bathymetric profile of a complex berm formation from multiple sets of co-located placements on Lines 2–6

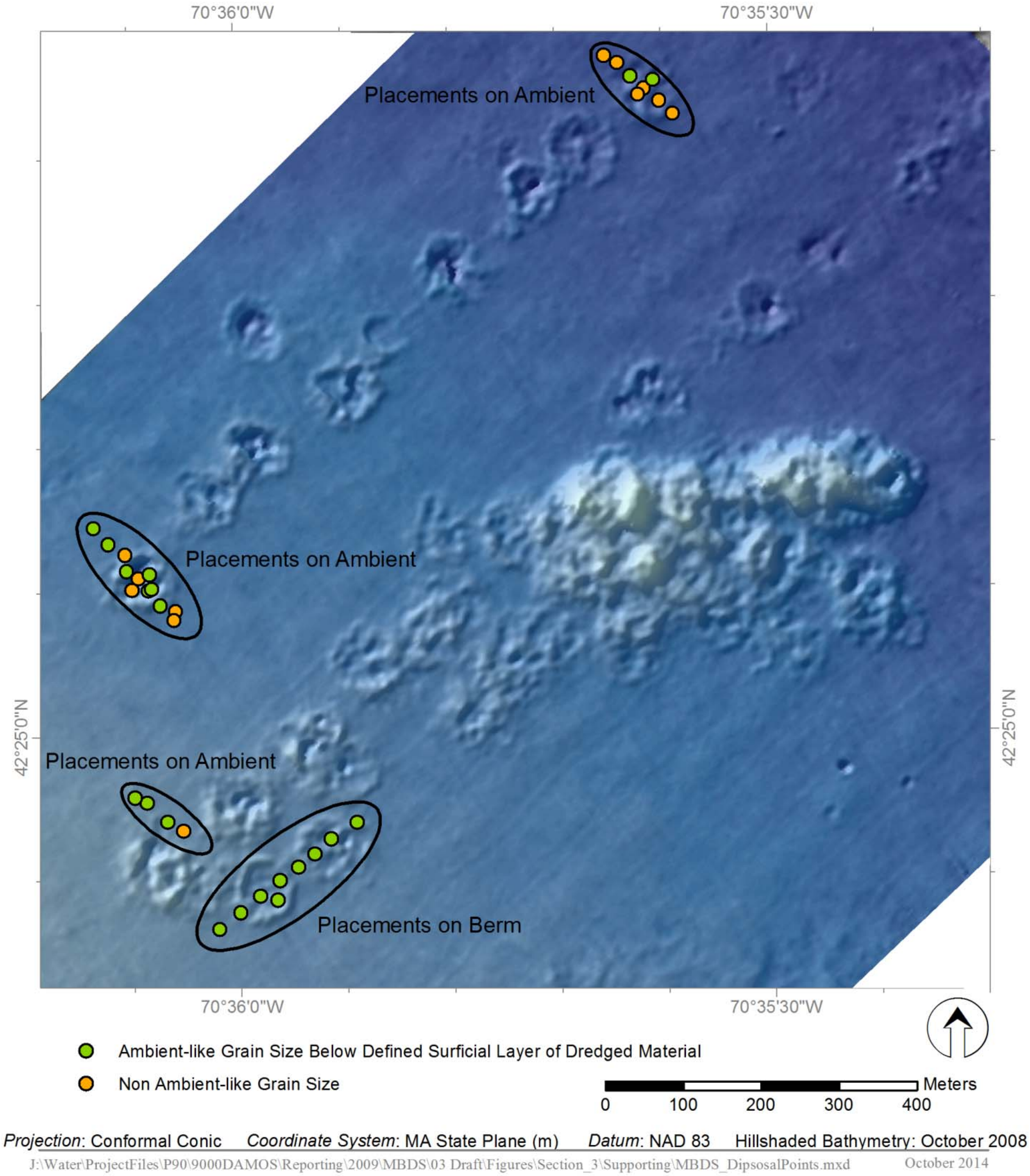

Figure 7-4: Grain size signatures in sediment core transects

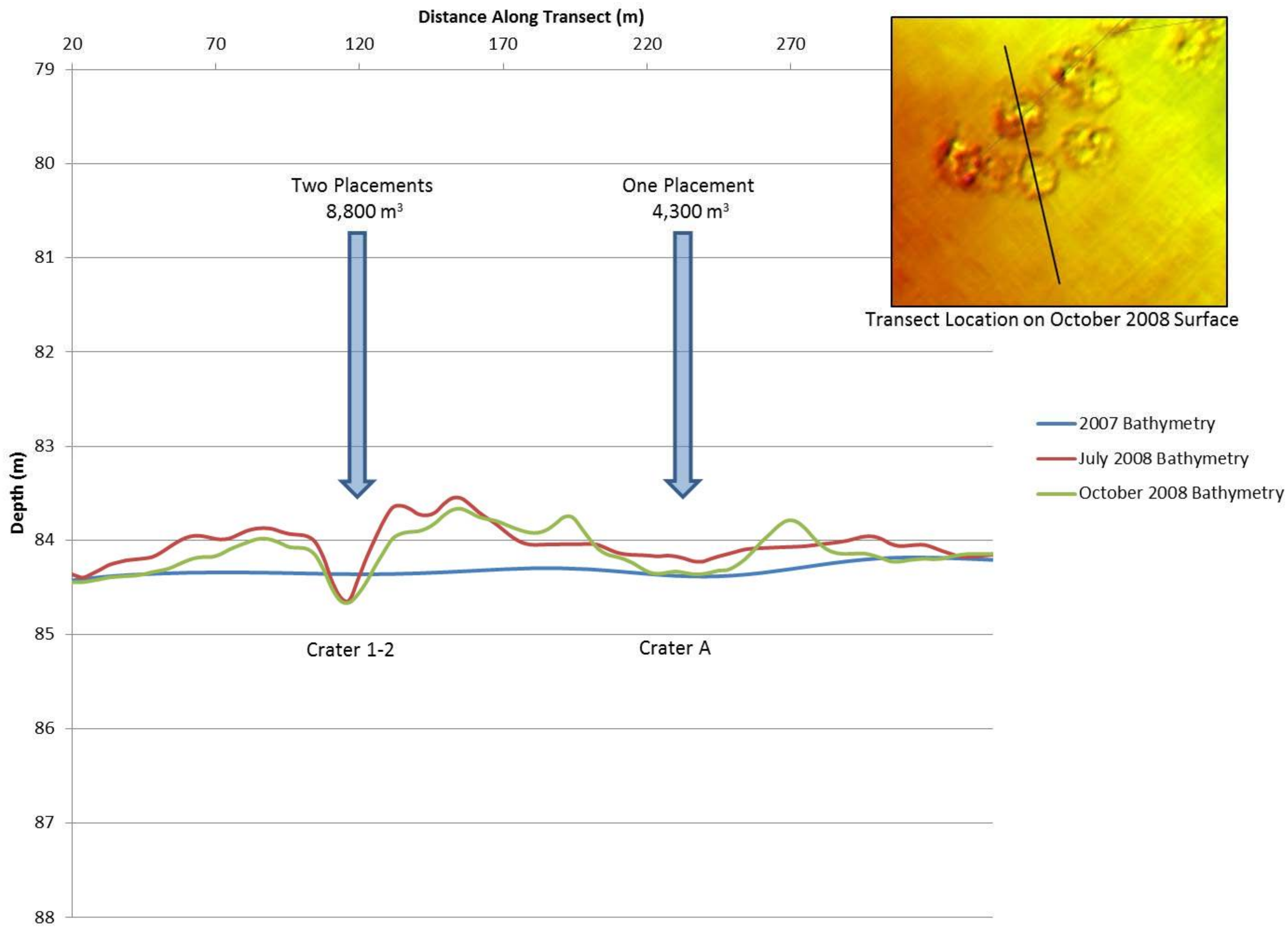

Figure 7-5: Bathymetric profile of a placement on a simple berm formation at crater A adjacent to Line 1

Table 7-1

Percent Grain Size Ranges from Ambient Core Samples

	Clay	Silt	Very Fine Sand	Fine Sand	Medium Sand	Coarse Sand	Very Coarse Sand
Min	5.6	66.1	7.1	0.3	0.0	0.0	0.0
Max	13.1	77.9	15.7	8.3	2.2	2.5	2.6

8.0 CONCLUSIONS AND RECOMMENDATIONS

8.1 Summary

The success of this demonstration project establishes an effective process to opportunistically use dredged material from the Boston Harbor deepening project for the restoration of the IWS.

- Simple target bearings and coordinates can be used by tug operators to implement the restoration approach and place dredged material in precise locations without impacting the schedule or costs of the dredging project.

- Sequenced placement of the Boston Blue Clay and glacial till generated from the Boston Harbor deepening project can be used to build berm of material at the IWS.

- A berm of dredged material provides sufficient protection from subsequent disposal events to limit the disturbance of in-place sediments or waste containers.

The sequential disposal approach outlined in this document minimizes the risk of disturbing in-place sediments or waste containers at the IWS while providing an effective cover to isolate those containers from potential environmental or human exposure.

8.2 Recommendations for Implementation

In order to implement the restoration approach outlined by this demonstration project several components will need to be addressed.

- *Environmental Assessment:* An Environmental Assessment will need to be written to determine any adverse impacts associated with the necessary expansion of the designated disposal boundary for MBDS. This expansion of the disposal site would allow for legal disposal of the cover material in the portions of the barrel field that are outside of the current MBDS footprint (Figure 6-3).

- *Final Design:* A final design for the restoration approach will need to be developed. This design should take in to consideration the barrel targets identified through previous side-scan sonar surveys, as well as the available volume of cover material, to classify priority areas for restoration. The design will also need to expand on the empirical data gathered through this demonstration project to determine appropriate thickness of cover material deposits to adequately isolate the waste containers (mean height above the seafloor of approximately 0.2 m) from the environment and any potential future disturbance from fishing activities.

- *Operational Plan:* In addition to developing final cover dimensions, an operational plan will need to be written to establish barge disposal sequencing and target spacing. The demonstration project established that two sequential disposals at a single target point created a usable berm approximately 0.3 m thick. Due to irregularities in berm cover it may be necessary to increase the target berm thickness to 0.5–1.0 m by placing additional disposals at each location before beginning disposals on the berm. This could also be achieved by moving the berm disposal targets closer to the original impact points; Crater A was approximately 115 m from the original impact point and this distance could be reduced to take advantage of a thicker berm closer to the original impact point.

- *Monitoring Plan:* In order to ensure accurate material placement, sequencing, and cover depths; a monitoring plan will need to be developed and executed in conjunction with the restoration project. Based on the results from the demonstration project it may be adequate to rely on acoustic survey techniques, such as multibeam bathymetry and side-scan sonar, to determine material placement performance. Likely cover scenarios (0.5–1.0 m thick) would be discernible though acoustic data collection which would maximize survey efficiency and real time reporting; minimizing schedule delays for the restoration operation. Utilizing acoustic technology would also eliminate the potential for other types of invasive survey equipment (sediment cores, sediment-profile imaging cameras, etc.) from disturbing the in-place sediments or waste containers.

- *Other factors:* Potential operational impacts to archeological resources (shipwrecks), commercial fishing activities, and adjacent infrastructure (liquefied natural gas terminals) will also need to be evaluated and considered during the design of the restoration project.

Based on these considerations, the restoration goals of the project, and the available material from Boston Harbor; a conceptual design for the restoration of the IWS could involve covering the high density waste container fields in EPA Priority Areas 1 and 2 (Figures 6-3 and 6-4). The extent of the restoration effort would be defined by the sharp drop in barrel density observed in Priority Area 3 and to the north and west of Priority Areas 1 and 2. This restoration approach would successfully cover the majority of the identified waste containers at the IWS and completely avoid all but two of the mapped shipwrecks in the vicinity (Figure 8-1). Prior to final design, the two shipwrecks potentially impacted from the project should be surveyed in detail through side-scan sonar or ROV inspection to determine the significance of the artifacts and if the restoration approach should be revised to avoid these resources.

The proposed area encompasses approximately 2.6 km^2 (0.76 nmi^2) which would require approximately 4.8 million m^3 (6.2 million yds^3) of dredged material to cover with a 1.0 m thick layer of sediment (assuming a 50% expression of volume as observed in the demonstration project). The Boston Harbor project will generate approximately 9 million m^3 (12 million yds^3) of ordinary dredged material, the majority of which is expected to be Boston Blue Clay that could be utilized for the restoration of the IWS.

8.3 Conclusions

The future deepening of Boston Harbor provides a unique opportunity to finally address the radioactive waste that was disposed at the historic Industrial Waste Site 70 years ago. This demonstration project outlines an approach that utilizes the available sediments from Boston Harbor to strategically cover the waste containers while minimizing the disturbance to the in-place sediments or containers themselves. The controlled and sequential placement of cover material can be used as a management tool to restore the IWS and isolate the radioactive containers at the site from potential environmental and human exposure.

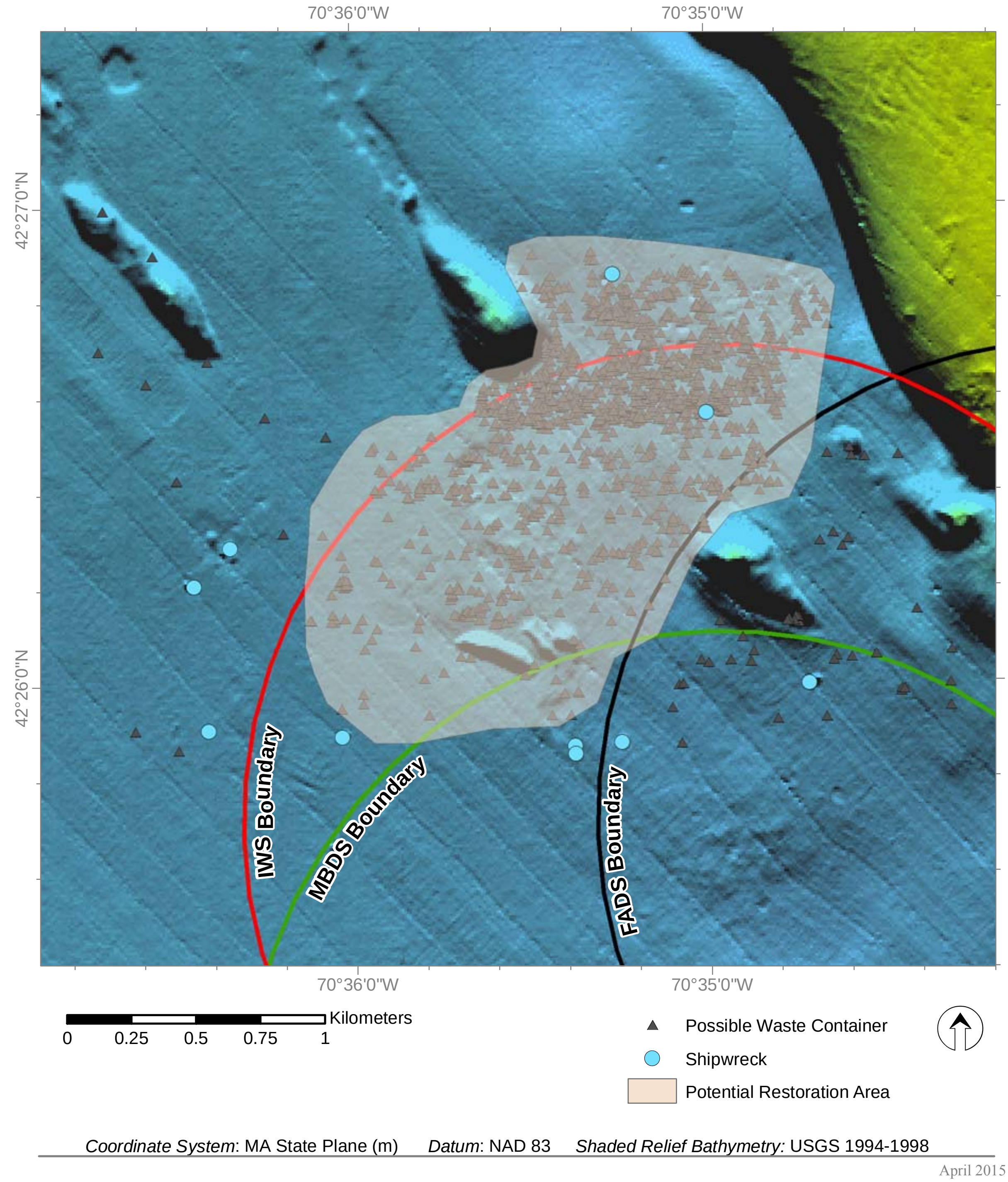

Figure 8-1: Potential restoration area at the IWS, showing distribution of likely waste containers and shipwrecks identified through EPA side-scan sonar surveys (2006 and 2010).

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