OCS STUDY
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ARCHAEOLOGICAL DAMAGE FROM OFFSHORE DREDGING: RECOMMENDATIONS FOR PRE-OPERATIONAL SURVEYS AND MITIGATION DURING DREDGING TO AVOID ADVERSE IMPACTS

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ARCHAEOLOGICAL DAMAGE FROM OFFSHORE DREDGING: RECOMMENDATIONS FOR PRE-OPERATIONAL SURVEYS AND MITIGATION DURING DREDGING TO AVOID ADVERSE IMPACTS

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LIST OF ACRONYMS

BMAPA	British Marine Aggregate Producers Association
B.P.	Before present
cm	centimeter
DGPS	Differential global positioning system
EDA	Exploratory data analysis
GIS	Geographic Information Systems
HIS	High Integrity Shipwreck
km	kilometer
LIS	Low Integrity Shipwreck
m	meter
MIS	Moderate Integrity Shipwreck
mm	millimeter
MMS	Minerals Management Service
NPS	National Park Service
OCS	Outer Continental Shelf
RCHME	Royal Commission on the Historical Monuments of England
RTK	Real-time kinematic
SHPO	State Historical Preservation Officer
TSHD	Trailing suction head dredge
USACE	U.S. Army Corps of Engineers

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1.0 INTRODUCTION

The U.S. Department of the Interior, specifically, the Minerals Management Service (MMS), has jurisdiction over all mineral resources on the United States Outer Continental Shelf (OCS). Public Law 103-426 gives MMS the authority to convey the rights to OCS sand, shell, or gravel resources for shore protection, beach or wetlands restoration projects, or for use in construction projects funded in whole or in part as authorized by the Federal Government.

Extensive beach nourishment projects on the East and Gulf Coasts are depleting known sand sources within the jurisdiction of the individual States (up to 3 nautical miles offshore). Assessment of potential sand resources in Federal waters have encouraged both the development of new resources and further restoration projects.

The National Historic Preservation Act requires federal agencies to protect historic and cultural resources which include shipwrecks, historic fortifications, and coastal settlements, as well as prehistoric sites that have become submerged due to the global and local rise in sea level. As a federal agency, the MMS must protect the significant archaeological and historic sites that maybe impacted by its activities. In addition, regardless of the historical significance of a shipwreck or site, these structures provide fish habitat and are considered potential Essential Fish Habitat. These structures can, and in many cases do, support sport fishing and diving industries.

In keeping with its mandate to protect archaeological and historic cultural resources, the MMS has commissioned this study to review its current practices and procedures. This study is focused on the operation of dredges mining sand and gravel in the OCS for aggregates and for beach nourishment projects. In the last two decades, most sand mining has been for beach nourishment projects on the East and Gulf coasts. The study consisted of the following tasks:

- Review of the worldwide literature to determine current dredging practices in other countries. It should be noted that dredging on the OCS is restricted to dredging companies owned mainly by citizens of the United States. The dredge must also have its hull constructed in the United States;
- Review of the literature on the nature and type of submerged cultural resources likely to be encountered on the continental shelf;
- Review of the methods and technology for locating and identifying submerged cultural resources, as well as the current MMS criteria for remote-sensing surveys;
- Review of reports of cultural resources damaged by dredging operations and the reasons the damage occurred;
- Canvass the dredging industry to determine the current practices and procedures for mining sand. This effort concentrated on equipment and accuracy of the dredging process;
- Review of mitigation requirements of other jurisdictions to prevent adverse impacts on submerged resources. Particular emphasis was placed on buffer or exclusion zones; and
- Synthesis of the study results into a set of recommendations on dredging methods, protocols, policies, and monitoring requirements to minimize impacts on submerged cultural resources.

The technical team who contributed to this report are:

Jacqueline Michel, Ph.D., Research Planning, Inc. – Principal Investigator and Editor;

Gordon P. Watts, Jr., Ph.D., Tidewater Atlantic Research, Inc. – Principal Investigator and Author of the cultural resources portion of the report;

Charles Pearson, Coastal Environments, Inc., and Michael Faught, Florida State University – Contributed ideas and text to the prehistoric sections of the report;

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Fernando G. Marvan, Ph.D., Baird and Associates, Inc. - Literature review and development of relationship between resource location and the dredge limit line;

Michael Fullarton, MSCE, Baird and Associates, Inc. - Assessment of sedimentation by application of the plume model for trailing suction hopper dredges.

2.0 METHODS OF STUDY

2.1 Worldwide Review of Current Dredging Practices

In preparing the inquiry to be sent to dredging contractors, it was necessary to determine the location of the potential borrow sites. Based on a review of current MMS literature, Table 1 shows the major borrow sites on the East and Gulf Coast (Research Planning, Inc. et al., 2001). An average site along the Atlantic coast would be approximately 12 kilometers (km) offshore in about 17 m of water. These distances and depths of water are within the capabilities of a modern Trailing Suction Hopper Dredge (TSHD). The Louisiana site is in relatively shallow water. This site may be better suited to mining by a Cutter Suction Dredge loading shallow draft barges. This information was summarized and incorporated into a letter and questionnaire to dredging and aggregate companies worldwide (see Appendix A).

TABLE 1. Location of the major OCS borrow sites along the East and Gulf of Mexico coasts.

State	No. of Sites	Kilometers offshore	Depth of water (m)	Quantity (millions of m^3)
New Jersey	4	5 to 20	< 20	94
Maryland/Delaware	3	10 to 16	5 to 20	350
Virginia	1 (Sandbridge)	10 to 13		33
North Carolina	4	7 to 15	15 to 25	255
South Carolina	1 (Myrtle Beach)			46
Florida	5 Counties	11 to 13	15 to 20	
Alabama	3	7 to 15	12 to 20	13
Louisiana	1 (Ship Shoal)	13 to 17	4	1,330

2.2 Archaeological Review Methods

A literature survey was conducted to identify publications, reports, legislation, and regulations that relate to the nature and scope of submerged cultural resources on the continental shelf, the most effective methods and technology for identifying those resources, the impacts of dredging activity, and means of protecting those sites from dredging activities. Libraries searched included Tidewater Atlantic Research, Inc. (TAR), East Carolina University, Texas A&M University, University of Florida, Florida State University, University of California-Berkeley, University of Rhode Island, and the University of Maryland. Many literature sources associated with the issues under consideration were found through Internet sources. Outside the United States, the most comprehensive government and industry response to issues related to offshore dredging appears to be Great Britain. The Royal Commission on the Historical Monuments of England (RCHME) and the British Marine Aggregate Producers Association (BMAPA) have joined in defining a national policy for the identification and protection of submerged cultural resources in areas where marine aggregates are dredged (Wessex Archaeology, 2003).

Contacts were made with personnel from federal agencies such as the U.S. Army Corps of Engineers (USACE), National Park Service (NPS), MMS, U.S. Navy, various State Historic Preservation Offices (SHPO), foreign agencies with management responsibility for submerged cultural resources, and private firms with experience in the conduct of submerged cultural resource research. Today, many state and federal agencies post regulations on submerged cultural resources and survey criteria on the Internet. Information from MMS that defines the agency's current submerged cultural resource related policies and procedures is available at http://www.gomr.mms.gov/homepg/regulate/regs/ntls/ntl02-g01.html.

To assess the state-of-the-art technology, available technical literature was examined and both manufacturers and users of remote-sensing equipment were contacted. Issues specific to submerged cultural resource location, identification, and assessment were identified and discussed with productive contacts. Trade literature such as *Sea Technology*, *Ocean News*, and *International Ocean Systems* proved to be extremely helpful in assessing the spectrum of remote-sensing equipment available for submerged cultural resource surveys. Product-specific information was found on web sites of manufacturers of magnetometers, sonars, subbottom profilers, multibeam and single beam echo sounders, global positioning systems, and survey software.

To expand contacts, a document identifying the proposed project objectives was prepared and distributed at the Society for Historical Archaeology annual conference held at Providence, Rhode Island in January 2003. That questionnaire was followed by an identical survey form (see Appendix B) distributed via the Internet to personnel at state and federal agencies, institutions and private companies involved in underwater archaeology and/or submerged cultural resource protection and management. Finally, many specific issues were the subject of follow-up Internet and telephone contacts.

3.0 THE NATURE OF SUBMERGED CULTURAL RESOURCES

Submerged cultural resources on the OCS can be classified broadly as shipwreck remains and inundated prehistoric sites. Additional cultural material reflects debris associated with modern maritime activities. Shipwrecks can be classified according to an almost infinite spectrum of criteria. However, for the purpose of this study, they are classified according to three levels of structural and archaeological integrity. Those classifications also reflect the type of remote sensing signatures that are generated by wreck remains. Inundated prehistoric sites vary in accordance with the human activity they reflect. Unlike shipwreck remains, prehistoric sites are subtle and more difficult to locate and identify.

3.1 Inundated Prehistoric Sites

3.1.1 OCS Habitation Hypothesis and Lower Sea-level Stands

About 20,000 year ago, at the height of the last major glaciation, the Late Wisconsinan, sea level was as much as 100 to 120 meters (m) lower than present. Throughout the Holocene (since about 10,000 years ago), sea level has undergone a net rise, the rate of which has varied from as much as 10 millimeters (mm) per year to as little as 1 mm per year. The current state of sea level change is the matter of some debate but it is generally thought that, on a global scale, the transgression continues albeit slowly. The Holocene transgression has resulted in the landward migration of coastal habitats across the shelf and, in some cases, submergence and preservation of geomorphic features and landforms. Relative sea level varied considerably along the Atlantic and Gulf coasts: In the Northeast, paleo-landscapes were depressed by glacial isostatic pressure; in the Gulf of Mexico paleo-landscapes were depressed by tectonic processes and sediment loading associated with the abandoned lobes of the Mississippi River delta.

Although scientific data concerning prehistoric sites on the OCS are limited, archaeologists have theorized for decades that prehistoric inhabitants of North America populated present-day continental shelf areas during the Late Wisconsin lower sea level (Goggin, 1962; Bullen et al., 1968; Bullen, 1969; Roberts, 1979; Cockrell, 1981; Kraft et al., 1983; Stright, 1987; Bonnichsen et al., 1987; Anuskiewicz, 1988; Faught, in press). Recently, archaeologists have hypothesized that early populations migrated and colonized the hemisphere from the continental shelves (Anderson and Faught, 1998; Anderson and Gillam, 2000; Faught, 1996; Dixon, 1999).

The low sea-level stands during and following the Wisconsin glaciation is an important factor for determining the potential for prehistoric sites on drowned continental shelf surfaces (Murphy, 1990). The development of vegetation and adaptation of natural resources would have made the exposed continental shelf attractive to human populations (Fisk and McFarlan, 1955). Those paleo-environmental conditions provide the basis for theories concerning prehistoric subsistence and settlement patterns that are extrapolated for the continental shelf (Bullen et al., 1968; Science Applications, Inc., 1981; Cockrell, 1980; Belknap, 1983; Bonnichsen et al., 1987). Sea-level fluctuation (Fig. 1) and its role in archaeological interpretation were first postulated by Goggin (1962). Emery and Edwards (1966) established a relative sea level curve and noted its

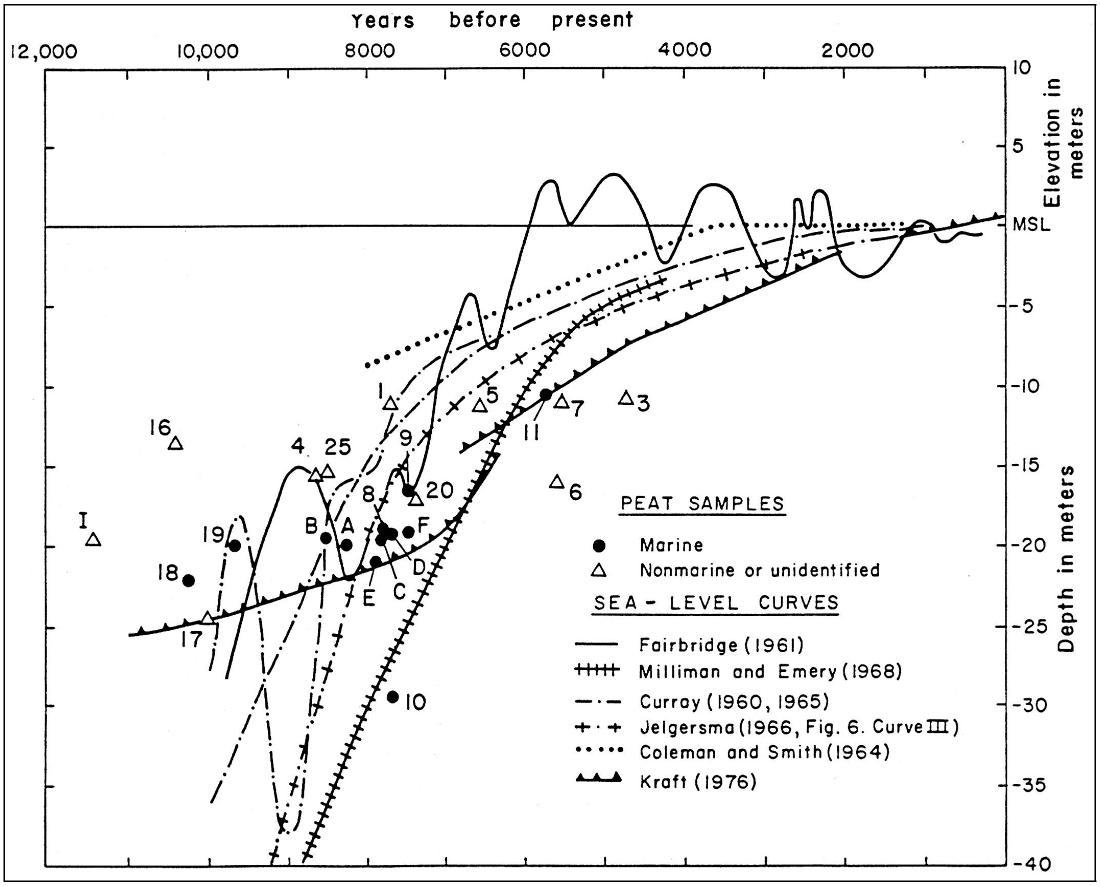

FIGURE 1. Sea-level curve showing the rapid rise in sea level at the end of the Late Wisconsinian glaciation, starting about 10,000 years ago (Murphy, 1990).

implications for inundated archaeological sites in relationship to the basic chronology of prehistory (Table 2). Paleoindian and Archaic sites were most likely submerged offshore, and sites of particular periods could be located at specific depths.

3.1.2 Submerged Cultural Resource Baseline Studies

While the amount of actual submerged cultural resource research on the continental shelf has been limited outside the Gulf of Mexico, the potential for prehistoric and historic archaeological sites has been the subject of both hypothesis and a number of detailed studies (Bourque, 1979; Science Applications, Inc., 1981; Coastal Environments, Inc., 1977; Garrison, 1989; Pearson et al., 2003). These studies, commissioned to establish baselines for submerged cultural resource management policy by agencies responsible for those resources, are summarized by region in the following paragraphs.

TABLE 2. Prehistoric chronology (modified from McNamara, 1978).

Cultural Period	Approximate Date	Settlement and Subsistence	Characteristic Artifact
Late Woodland	A.D. 800 to A.D. 1600	More sedentary settlement along major river systems culminating in fortified villages; subsistence based on hunting and gathering including anadromous fish and shellfish; introduction of horticulture.	Ceramics: 1) crushed shell-tempered, fabric impressed, incised rim decoration, conoidal vessels and 2) thin hard crushed quartz, chord-marked, conoidal vessels. Projectile Points: Small quartz triangle points.
Middle Woodland	300 B.C. to A.D. 800	Sedentary settlement along the Bay and major coastal rivers. Strong dependence on oyster; limited hunting and gathering; anadromous fish (seasonal food source)	Ceramics: 1) crushed quartz and 2) small percentage of crushed shell tempering, cord-marked or net-impressed, conoidal vessels. Projectile Points: medium sized, thin, broad-bladed, side-notched or broad, straight-stemmed rhyolite points.
Early Woodland	1000 B.C. to 300 B.C.	Settlement along major river systems; increased dependence on oyster along with hunting and gathering; anadromous fish (seasonal food source.	Ceramics: 1) steatite tempered, plain or chord-marked, flat-bottomed or conoidal vessels; 2) grit or sand-tempered, chord-marked or net-impressed, conoidal vessels. Projectile Points: small, triangular blade, straight-stemmed, cryptocrystalline and quartz (persistence of some Late Archaic point forms).
Late Archaic (Transitional)	3000 B.C. to 1000 B.C.	Shift from semi-nomadic subsistence pattern to a more sedentary existence; begin to exploit coastal riverine resources; anadromous fish and oysters.	Susquehanna Broadspear Tradition: Soapstone bowls and medium sized, broad-bladed, rhyolite & quartz projectile points and quartzite fishtail points.
Middle Archaic	6000 B.C. to 3000 B.C.	Semi-nomadic existence within a defined territory; hunting and gathering keyed to seasonal abundance of flora and fauna.	Projectile Points: 1) broad triangular blade with a small square stem & a shallow notched base (Stanley Stemmed); 2) long narrow or a small triangular blade with a long narrow or short pointed stem (Morrow Mountain I & II); 3) long, slender, but thick blade with straight rounded or concave base (Guilford), quartz and quartzite in common use.
Early Archaic	8000 B.C. to 6000 B.C.	Semi-nomadic existence within a defined territory; hunting and gathering keyed to seasonal abundance of flora & fauna.	Projectile Points: 1) small, thin bifurcated point with serrated edges (Lecroy); 2) a large triangular blade with a straight base, corner-notched, and serrated edges (also have a side-notched form) (Kirk); 3) small, corner-notched blade with a straight, ground base & pronounced serrations, cryptocrystalline and rhyolite in common usage.
Paleo-Indian	10000 B.C. to 8000 B.C.	Semi-nomadic existence within a defined territory, emphasis on hunting over gathering; large grassland adapted fauna; dependent on local sources of cryptocrystalline stone.	Projectile Point: narrow, fluted, lanceolate points of medium to large size with ground, concave bases, cryptocrystalline in common use.

The Gulf of Mexico cultural resources baseline study was carried out for the NPS and published in 1977. One of the most important management tools produced by this study was identification of high probability areas for both prehistoric and shipwreck submerged cultural resources (Coastal Environments, Inc., 1977).

The South Atlantic cultural resources baseline study covered the continental shelf between Cape Hatteras, North Carolina and Key West, Florida. The research and predictive models for south Atlantic submerged cultural resources were published in 1979 (Science Applications, Inc., 1981). The North Atlantic cultural resources baseline study covered the continental shelf between Cape Hatteras and the Bay of Fundy. The report identified high probability areas for both prehistoric and shipwreck submerged cultural resources (Bourque, 1979).

In the southern California shelf cultural resources baseline study, Pierson and Shiller (1989) synthesized historical, archaeological, and geological data to develop a predictive model for prehistoric and historic submerged cultural resources for the southern half of California. A baseline study for submerged cultural resources on the Pacific shelf along the coast of northern California, Oregon and Washington included a survey of literature and historical data sources, an inventory of lost ships and identification of high probability areas for both prehistoric and historic submerged cultural resources (Espy Huston & Associates, 1990). The Bering shelf study focused primarily on the potential for prehistoric submerged cultural resources, but found no evidence to “preclude the presence of shipwrecks” in the study area (Dixon, 1989). The Alaska OCS Region office of MMS developed an inventory of shipwrecks on the Alaskan shelf and shore in 1992 (MMS, 1992).

3.1.3 Testing and Refining the OCS Baseline Models for Prehistoric Sites

MMS funded, supported, and cooperated in four research projects designed to generate data useful in refining the hypotheses and predictive models generated by those baseline OCS studies. In the first study, Pearson et al. (1986) tested the model for site distribution and preservation in the Sabine-High Island area of the continental shelf off the Texas and Louisiana coasts. Based on an assessment and synthesis of data from MMS lease block surveys and other sources, they selected areas of high probability for more intensive seismic surveying and core sampling. Results of the study illustrated the association between relic landforms and submerged archaeological deposits, confirming that stratigraphy can survive inundation under certain conditions and validating the use of remote sensing and coring in surveys designed to identify prehistoric submerged cultural resources (Pearson et al., 1989).

In a second study, relic riverine channels and karst features along Florida Gulf coast that had been predicted to have a high probability of prehistoric sites were targeted. Investigation of a number of prehistoric sites in Apalachee Bay produced encouraging evidence that terrestrial predictive models were useful in locating submerged sites and suggested that high degrees of organic preservation were possible where stratigraphy has been preserved (Anuskiewicz, 1988; Faught, 1988; Dunbar, 1988; Dunbar et al., 1989).

In a third study, Garrison et al. (1989) initiated a re-examination of the probability study that formed the basis of establishing priorities for remote-sensing surveys in OCS lease blocks in the Gulf of Mexico. New data had been generated by a decade of historical research and remote-sensing surveys carried out in conjunction with MMS oil and gas permits. The study focused on problems of remote-sensing signature analysis associated with those lease-block investigations.

A 2003 study represented an extension of MMS efforts to revise and strengthen submerged cultural resource management policies. That project consisted of three components: 1) collecting additional shipwreck data to expand the MMS shipwreck database used for modeling; 2) correlating shipwreck data with site specific data from remote-sensing surveys in Gulf of Mexico lease blocks; and 3) revising the MMS predictive model based on those data. In addition, the project involved testing magnetometers and making recommendations for revised and improved survey strategies to identify submerged cultural resources (Pearson et al., 2003).

In 1989, NPS conducted an overall examination of the MMS submerged cultural resource management program and made recommendations for future priorities (Aten, 1989). This review recognized MMS-sponsored research carried out on the offshore relic channels of the Sabine River (Pearson et al., 1986) and assessments of coring analysis techniques (Gagliano et al., 1982; Pearson et al., 1986). Recommendations of the study called for more MMS-sponsored research and advised:

- Developing an offshore cultural resources protection plan and research design for the next decade;
- Establishing standards related to data collection to improve merging, consolidating, and synthesizing data on a regional basis;
- Undertaking regional synthesis of geomorphic and magnetic anomaly mapping to facilitate lease block specific analysis;
- Creating and maintaining small contracts for dating and analysis;
- Developing new refined submerged cultural resource probability maps integrated with high probability mineral resource deposits; and
- Expanding the focus to OCS cultural resource studies to produce more and better controlled paleo-environmental data.

3.1.4 Dredging and Initial Evidence of Inundated Prehistoric Habitation

The first physical evidence of prehistoric activity on the continental shelf appeared inadvertently. Dredging along coastal margin zones to support increasing harbor development and demands for shore protection disturbed prehistoric deposits on occasion. Commercial dredging of oyster shell beds beneath Tampa Bay in the 1950s and 1960s exposed numerous artifacts mixed with shell from midden contexts. Artifacts included those diagnostic of Paleoindian and Early Archaic presence, and Mid-Archaic through Late Archaic items (Warren, 1964; Goodyear and Warren, 1972; Goodyear et al., 1983). Dredged sediment pumped onto Apollo Beach, Florida contained artifacts including mid-Archaic (Culbreath) points and both fiber and sand tempered ceramics (Warren, 1968b). At Turtlecrawl Point, material dredged up for the construction of an artificial peninsula contained cultural material that included Greenbriar and Bolen (early Archaic) lithic material, unifacial tools, a Dalton adze, as well as middle archaic Morrow Mountain and Newnan points (Goodyear, 1980). At Terra Ceia Bay, Florida materials dredged for beach nourishment contained artifacts including Dalton and Greenbriar points, a turtle back scraper, lithic tools, ceramics, and extinct faunal remains (Bullen, 1951). Suwannee (Paleoindian) and Bolen (early Archaic) points were uncovered during dredging at Caladesi Causeway, Florida (Warren, 1968a).

Lithic material suggestive of tools or the tool-making process and dating to the period from 13,000 to 10,000 years B.P. was recovered from dredge spoil from Galveston Bay, Texas (Aten, 1983). Stright (1990) noted the uncovering of Archaic period material in Long Island Sound associated with dredging activities. Beach nourishment activities at Monmouth Beach, New Jersey revealed a collection of prehistoric artifacts within recently deposited sand. The sand source was traced to a borrow area lying in 10-12 m of water approximately 1.5 km offshore. The material was believed to have originated within the first 1.5 m of the seabed (Tuttle, 2001).

3.1.5 Recent Evidence of Inundated Prehistoric Habitation in the OCS

Recent research on submerged sites along the northeastern Gulf of Mexico has been carried out by researchers at Florida State University who have searched for prehistoric sites along the margins of the drowned Aucilla River by employing models used for locating such sites in terrestrial settings (Faught and Latvis, 2000; Faught, 2001). The paleo-landscape setting has been reconstructed by remote sensing with sidescan sonar and subbottom profiler, in conjunction with precise bathymetry. Terrestrial analogs from the local karst terrestrial archaeological record have proven effective in identifying 39 sites on inshore areas of the continental shelf. More than 4,500 stone artifacts, including diagnostic projectile points, formal chipped stone tools, and abundant debitage have been recovered. Abundant artifacts in dense arrays have been found at sites located between 6.4-16.5 km offshore in water depths of 3.6-5.5 m. Ancillary geoarchaeological data include faunal bone, wood, mollusks, and sediment samples (www.adp.fsu.edu/clovis/clovis.field). This research supports theories that submerged sites, like their terrestrial counterparts, are found on sandy ridges near river and creek channels (Faught, 2003).

The potential for survival of prehistoric sites in high-energy Atlantic coastal environments has been considered low (Emery and Edwards, 1966; Waters, 1992). However, research along the Florida east coast and accidental finds off the Mid-Atlantic indicate that this is not necessarily the case. Material found at the Douglass Beach Site (8SL17), near Fort Pierce, Florida provides information on conditions for the survival of such resources on the Atlantic seaboard. Radiocarbon analysis indicates that the site was occupied during the Middle Archaic and consisted of faunal material, ceramics, stone tools, and human remains. The survival of the artifacts appears to have been the result of a unique coastal formation (Cockrell and Murphy, 1978). The site is located within sediment filled depressions on a hard coquina base. These sediments are overlain by a layer of dark gray-green clay, which is in turn capped by a gray deposit of possible lagoonal origin. A series of parallel dead coral reefs atop the site may have dampened local wave action, allowing for resource preservation (Stright, 1990; Waters, 1992).

During the summer of 2003, staff and students in a field school operated by the State University of New York, Stony Brook carried out a survey off the New Jersey coast in conjunction with the NPS Gateway National Recreation Area. The survey was designed to identify the source of prehistoric cultural material previously pumped onto the beach at Monmouth, New Jersey (Hanley, 2003). The volume of material recovered on-shore suggested that a valuable site had been located in the sand borrow area. While both Archaic and Woodland material was present, it appeared that an Archaic period site had been destroyed (Tuttle, 2001).

3.1.6 Paleo-landforms with High Probability of Prehistoric Sites in the OCS

One important principle that has come from theorizing about the locations of submerged prehistoric sites is that particular landforms are associated with particular kinds of archaeological sites. These are known as "terrestrial analogs." Land-use patterns from archaeological evidence associated with terrestrial prehistoric sites (Gardner, 1980; 1982) can be used to identify potential habitation sites on the OCS (Bullen et al., 1968; Science Applications, Inc., 1981; Cockrell, 1980; Belknap, 1983; Bonnichsen et al., 1987; Faught and Latvis, 2000; Faught, 2003). Table 3 lists the specific landforms that may be reflectors of site topology (Dragoo, 1976; Science Applications, Inc., 1981; Waters, 1992; Faught, 2003).

The fact that relic estuary complexes could contain the remains of prehistoric vessels is reinforced by the examples of prehistoric canoes that have been found in lakes and rivers in Florida, South Carolina, North Carolina and Virginia (Watts, 1975; Bright, 1987; Bullen and Brooks, 1968; Amer, 1992; McCary, 1964).

TABLE 3. Relic landforms that may be preserved on the OCS and the types of prehistoric sites that may be associated with them, based on terrestrial analogs.

Relic Landforms	Site Types
Relic River and Stream Channels (seasonally dry)	Kill Sites Resource Procurement Waste Deposits
Relic River and Stream Channels (active flow)	Fishing Resource Procurement Manufacturing Loci Transportation (vessels)
Relic Estuary Complexes	Fishing Kill Sites Middens Transportation (vessels)
Relic Berms, Dunes and Hammocks	Habitation Sites Kill Sites Seasonal Camps Manufacturing Loci

3.1.7 Potential for Preservation of the Prehistoric Archaeological Record

Originally, many researchers speculated "that little might remain offshore beyond some tools, because of the advancing seas and the scattering of materials produced by the passage of the surf zone over the sites" (Murphy, 1990). Others, however, have postulated that deltaic and estuarine sediment deposition associated with rising sea level was possibly protecting sites from erosion associated with the Holocene transgression (Belknap, 1983; Waters, 1992). While the issues of *in-situ* archaeological integrity and stratigraphic preservation remain to be answered, preliminary research suggests that, under certain circumstances, the dynamics of the inundation process do not re-sort or destroy the interrelationship of material reflecting patterns of human behavior. The survival of prehistoric cultural material associated with human occupation sites of the Gulf continental shelf has been documented from Florida to Texas (Koski, 1986; 1988; Anuskiewicz et al., 1988; 1994; Aten and Good, 1985; Stright, 1990; Johnson, 1991; Faught and Latvis, 2000; Faught, in press). Stright (1990; 1995) published articles on inshore prehistoric sites on the North American continental shelf, and Merwin (2003) recently carried out a survey off the New Jersey coast to identify the source of prehistoric material deposited on shore by beach nourishment. Material identified to date spans the Pleistocene, Archaic, and Early Woodland periods (Merwin, in press).

In one well-documented study, Pearson et al. (1986) found submerged prehistoric material in association with relic features of the Sabine River. Those remains included subaerial shell middens and associated pollen deposits that reflect features associated with terrestrial archaeological sites. The relic Sabine River deposits were identified approximately 16.5-18 m below present sea level and 4.5-6 m below the seafloor. Material recovered from the deposit was dated approximately 8,100 years B.P. using radiocarbon analysis (Pearson et al., 1986).

In all likelihood, the archaeological integrity of sites in the inshore shallows, the surf zone, or on the beach does not survive. That area is dynamic and remains in a constant state of flux. As a consequence, evidence of prehistoric activity is likely to be limited to lithic and ceramic materials that have little or no provenience. One possible exception is where cultural material survives in association with denser sediments that are more resistant to reworking by waves.

3.1.8 Technologies for the Search for Inundated Prehistoric Sites

Because early prehistoric archaeological resources are virtually invisible to remote sensing, their association with relic landforms appears to be the key to locating and identifying areas of high potential. The Sabine River study carried out by Pearson et al. (1986) almost two decades ago and current research carried out by Faught (2003) provide the most convincing evidence of the value of that correlation.

In conducting surveys designed to identify relic landforms and prehistoric archaeological sites, acoustic instruments appear to be the most effective (Hoyt et al., 1990). The three instruments that generate the most useful data are sidescan sonars, multibeam echo sounders, and subbottom profilers. The sidescan sonar and multibeam echo sounders generate high-resolution data that can be used to reconstruct and map surface geological features that reflect paleo-topography. Used in conjunction with highly sophisticated terrain modeling programs, acoustic data from those instruments can be turned into highly detailed bottom surface maps that cover broad areas.

Characteristics of the bottom surface can be associated with buried geomorphological features using high-resolution subbottom profilers. With sufficient data, sophisticated computer modeling programs can be used to develop three-dimensional, geo-referenced models of relic landforms that could be associated with prehistoric archaeological sites. The horizontal and vertical extent of dredge cuts are programmed into a three-dimensional computer model of the deposit and geographical coordinates are fed into the dredge navigation and excavation systems (Kniesley, 2004; Andrews, 2004). This method is currently being employed to identify the parameters of deposits of beach nourishment sand so that dredging activity will not produce undesirable material. Figure 2 shows an example of this approach applied to dredging of the offshore, buried fluvial system that provided sand for nourishing Holly Beach, Louisiana. Seismic data from the cultural resource and shallow hazard investigation were combined with data from the geotechnical sand search investigation to refine the borrow area design around material suitable for beach nourishment. The combination of data produced a much more accurate definition of relic landforms and will permit dredging to be limited to the stratigraphic layers that contain that material. The more intensive survey line spacing is clearly necessary for identifying and delineating relic landforms that have a potential association with prehistoric submerged cultural resources. In addition that level of definition will be essential for the effective development of buffer zones to protect features with prehistoric potential.

Using Geographic Information Systems (GIS) and sophisticated dredging software to store, analyze, and project geophysical data, archaeologists and submerged cultural resource managers can identify areas with prehistoric potential for research or protection. That level of stratigraphic definition and dredging control would permit feature-specific dredge sampling designed to test the application of terrestrial analogs to the continental shelf environment.

3.2 Shipwreck Remains

The remains of thousands of historic and modern vessels lie on the North American continental shelf and in the shallow waters adjacent to coastal beaches. Shipwreck remains should be expected in any of the proposed borrow areas on the Atlantic and Gulf of Mexico continental shelves.

Historical research does not identify acurately the specific locations of vessels sunk offshore, but the intensity of maritime commerce and the volume of historically documented vessel losses confirm that those resources are present (Bourque, 1979; Coastal Environments, Inc., 1977; Science Applications, 1981; Garrison, 1989; Pearson et al., 2003). Shipwreck remains must also be anticipated in any of the areas adjacent to or on beaches where dredged sand will be deposited. Documented vessel losses and recorded sites on shore confirm that shipwreck resources are highly probable on beaches, in the intertidal zone, and in near shore waters (Delgado, 1984; Delgado and Murphy, 1984; Bright, 1993).

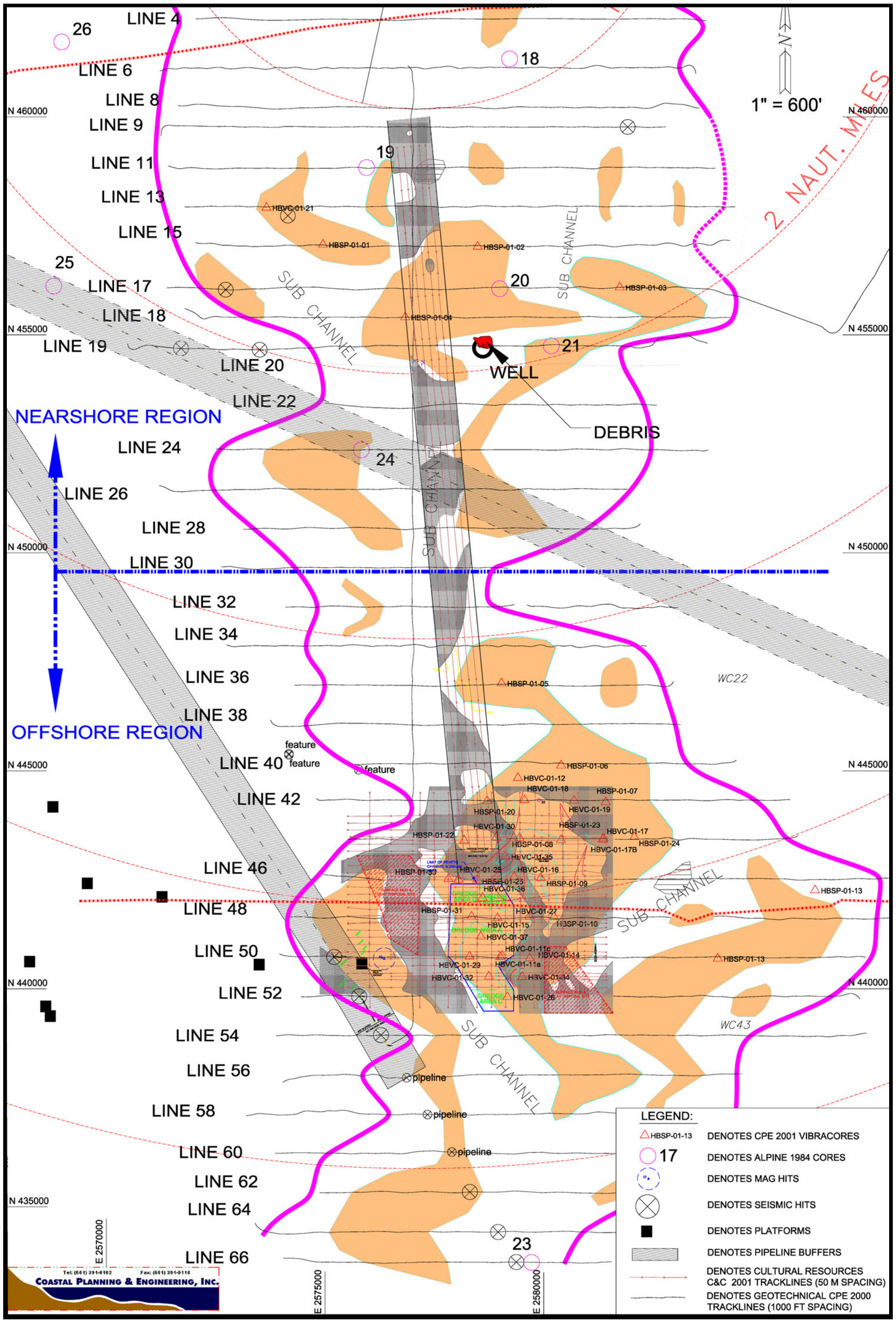

FIGURE 2. Map of the Holly Beach "fluvial system" at a 300 m spacing between tracklines for the geotechnical investigation and the higher density mapping (50 m) of the fluvial channels for cultural resources (in the south) in a proposed borrow area and overburden disposal site off Louisiana. With the more intensive survey, it was possible to delineate relic landforms with much greater detail, as seen in the southern area (Image courtesy of Coastal Planning & Engineering, Inc.).

3.2.1 Shipwreck Baseline Studies

A series of studies, carried out under the auspices of MMS in the 1970s, 1980s and 1990s, provide valuable insight into the patterns of navigation and ship losses on the Atlantic, Pacific and Gulf continental shelves. The North Atlantic study covered the area between the Bay of Fundy and Cape Hatteras, North Carolina (Bourgue, 1979). The South Atlantic study covered the cultural resources on the continental shelf between Cape Hatteras and Key West (Science Applications, Inc., 1981). The Gulf of Mexico study covered the cultural resources from Key West to the border with Mexico (Coastal Environments, Inc., 1977). The southern California study covered the shelf from Morro Bay to the Mexican border (PS Associates, 1987) and the northern Pacific shelf study focused on the coast of northern California, Oregon and Washington (Espy Huston & Associates, 1990). An inventory of shipwrecks off Alaska was compiled by the staff of the Alaska OCS Region (MMS, 1992).

The issue of Gulf of Mexico historic shipwrecks and their relationship to remote-sensing anomalies was given additional consideration in a re-evaluation of archaeological resource management carried out for MMS (Garrison, 1986; Garrison et al., 1989). The high-probability model for shipwrecks on the Gulf of Mexico OCS was refined and revised (Pearson et al., 2003). Those studies represent the basis for MMS submerged cultural resource management on the continental shelf.

A 2003 study represented an extension of MMS efforts to revise and strengthen submerged cultural resource management policies. That project consisted of three components: 1) collecting additional shipwreck data to expand the MMS shipwreck database used for modeling; 2) correlating shipwreck data with site specific data from remote-sensing surveys in Gulf of Mexico lease blocks; and 3) revising the MMS predictive model based on those data. In addition, the project involved testing magnetometers and making recommendations for revised and improved survey strategies to identify submerged cultural resources (Pearson et al., 2003).

3.2.2 Vessel Types Potentially Present in OCS Borrow Areas

Patterns of navigation on the waters of the Atlantic, Gulf of Mexico, and Pacific continental shelves date from early in the sixteenth century when European explorers began to investigate the New World in the wake of Columbus' discovery. During the sixteenth and seventeenth centuries, navigation increased as the efforts of Europeans shifted to conquest and colonization. Development of extensive colonial empires stimulated navigation associated with trade, transportation, communication, warfare, and fishing in the eighteenth century. By the time New World colonial empires developed autonomy in the late eighteenth and early nineteenth centuries, navigation in the Atlantic, Gulf of Mexico, and, to a somewhat lesser degree, the Pacific, reflected complex and extensive international commercial networks. Those networks were reinforced and expanded in the nineteenth and twentieth centuries by rapid technological developments such as steam power and modern shipbuilding practices (Bourque, 1979; Science Applications, Inc., 1981; Coastal Environments, Inc., 1977; Garrison, 1989; Pearson et al., 2003).

The documented patterns of maritime activity confirm that the entire spectrum of vessels employed in navigation on the Atlantic and in the Gulf of Mexico could be reflected in shipwreck remains found in the OCS sand borrow areas. During the Age of Exploration and early colonization, European vessel designs such as the caravel and carrack made trans-Atlantic exploration and settlement possible. The Atlantic environment necessitated changes in vessel design and construction. More seaworthy Spanish, French, and English galleons, square rigged caravels and pinaces, and Dutch fluyts supported transportation, trade, and warfare. As colonial empires in the New World became more complex and Atlantic navigation more systematic, the three-masted Atlantic ship became the dominant vessel rig.

During the seventeenth century, the territorial imperatives of European nations stimulated a distinct division between merchant vessels and warships. Trans-Atlantic merchant ships reflected the characteristics of the galleon but with expanding cargo capacity. Warships reflected the necessity to carry ship-killing ordnance into the open oceans. Both merchant ships and ships of the Line-of-Battle increased in size to the limits of technology. During the eighteenth century, the ship-rigged vessel remained the mainstay of transoceanic navigation. However, smaller vessels such as the brig, snow, ketch, sloop, and schooner became important elements of an expanding maritime tradition.

During the nineteenth century, technological advances and the industrial revolution stimulated dramatic changes in navigation. The construction of wooden ships reached its zenith in the form of massive warships and merchant clipper ships. The fore and aft schooner rig was used with increasing frequency on large oceanic vessels due to its improved performance to windward. The development of steam power and iron vessel construction were the dominant factors in dramatic changes in nineteenth century ship architecture and construction. By the end of the century, iron and steel hull steamers had become the dominant merchant ships and almost entirely displaced sailing vessels. Powerful wooden sailing warships that reflected centuries of tradition were made obsolete almost overnight by armored iron and steel ships powered entirely by steam. Experiments with submarines that first succeeded in sinking an enemy ship during the American Civil War evolved into a lethal new undersea weapon. In spite of the revolution in technology, craft such as the three-masted ship, brigs, brigantines, sloops, and schooners continued to serve the coastal trades and fishing industries.

Although steam-powered merchant ships carried the bulk of passengers and freight, merchant sail survived into the twentieth century. Large schooners and clipper ships continued to compete, carrying cargos that were less delivery critical. However, after the end of World War I, their role became infinitely less significant. Merchant steamers of perpetually increasing size dominated virtually all of the maritime trades except fishing. Warships, like merchant vessels, continued to evolve in size and become highly specialized in their operational role. Battleships, cruisers, and destroyers were joined by aircraft carriers prior to World War II. Fleets of submarines were built to take advantage of the development of efficient diesel and electric power. During World War I and to a greater degree during World War II, the Atlantic and Gulf of Mexico became the scene of intense submarine warfare. Numerous merchant ships and patrol craft were sunk by German submarines. More effective anti-submarine operations resulted in the destruction of German U-boats. Although post-World War II improvements in shipbuilding and navigation made maritime commerce much safer, storms and accidents continue to result in the loss of modern vessels engaged in commerce and the fishing industry.

As a consequence of those activities, the Atlantic, Gulf of Mexico, and Pacific continental shelves have become repositories for the remains of the entire spectrum of vessels that supported development of the Western Hemisphere (Bass, 1988). While the distribution of shipwreck sites on the continental shelf cannot be associated specifically with the submerged ridge and swale features that currently represent major sources of sand, those deposits lie amid the historic routes of navigation. Although shipwrecks are somewhat random in their areal distribution, it is generally accepted that higher densities exist in association with established navigation routes, environmental obstructions to navigation, and by inshore areas. Hypothetical models for shipwreck distribution have identified the waters offshore and in between ports as areas of high probability (Bourque, 1979; Science Applications, Inc., 1981; Coastal Environments, Inc., 1977). The OCS borrow areas under consideration lie among the most heavily utilized shipping routes in the Western Hemisphere. Historical research associated with submerged cultural resource baseline studies has identified those navigation routes as high-density areas for shipwrecks.

3.2.3 Classification of Shipwreck Remains

Shipwreck remains, regardless of their location, can be classified using three basic categories. Those three categories reflect the extent and condition of surviving structural remains, the extent and condition of material associated with the ships function, and, depending upon vessel type, the extent and condition of the vessel's cargo. These classifications also reflect the characteristics of remote sensing signatures likely to be associated with vessel remains. All three classifications of vessel remains could be present in the borrow areas identified by MMS.

3.2.3.1 High Integrity Shipwrecks

The first shipwreck classification, High Integrity Shipwreck (HIS), reflects the remains of vessels that sank relatively intact with a substantial portion of the original structure surviving. Not only does the surviving structure preserve a valuable architectural and construction record, material associated with the ship's function and cargo survive within, or in close association with the hull remains. In relatively shallow offshore waters, HIS shipwrecks probably represent the exception rather than the rule, and high integrity preservation could be associated with rapid settling of the wreck into bottom sediments. HIS shipwrecks frequently generate well-defined acoustic images and complicated localized magnetic signatures.

The remains of the ironclad USS *Monitor*, that sank relatively intact during a storm off Cape Hatteras in 1862, provide an excellent example of this type of site. The vessel foundered and settled upside down but virtually undamaged on the bottom in approximately 70 m of water. Although most of the vessel structure remained exposed in the water column, enough survived to preserve a record of design and construction. Within the surviving structure a complex archaeological record remained to document life aboard the vessel and the ship's function (Watts, 1982).

3.2.3.2 Moderate Integrity Shipwrecks

A second classification for shipwreck remains, Moderate Integrity Shipwreck (MIS), reflects the survival of substantial elements of the original vessel structure. The surviving hull remains would be sufficient to preserve a substantial record of architectural and construction details that could contribute to reconstruction efforts. A partial archaeological record associated with the ship's function and cargo would be present within, or in close diagnostic association with, the surviving structure. MIS shipwrecks generally produce less well-defined acoustic images and slightly less complicated but localized magnetic signatures.

The Spanish Plata Flota vessel *El Nuevo Constante* provides an example of the MIS type of site. *El Nuevo Constante* was lost off Louisiana during a storm in 1766. Surviving structural remains consisted of little more than the lower hull, however, the surviving structure preserved important architectural and construction details. An important collection of artifacts was recovered within and adjacent to the hull remains. Investigation of *El Nuevo Constante* produced important insight into the demise of the Plata Flota system and the economics of Spain's colonial empire in the mid-eighteenth century (Pearson and Hoffman, 1995).

3.2.3.3 Low Integrity Shipwreck Sites

The third classification for shipwreck remains, Low Integrity Shipwrecks (LIS), reflects more complete destruction of the vessel. This category would include ships broken up at sea, in the surf zone, and on shoals or other obstructions. The surviving archaeological record consists of little more than fragments of the vessel structure and a scatter of material associated with operation of the vessel or cargo. LIS shipwrecks may not produce any acoustic image and the images can consist of little more than a scatter of bottom surface material. The magnetic signatures associated with LIS sites are ordinarily scatters or clusters of anomalies that reflect the fragmented nature of structural remains and the distribution of fastenings, tackle, ordnance, cargo, and other materials.

Remains of the 1554 Spanish Plata Flota vessel *San Estaban* provide an excellent example of the LIS type of site. Material associated with that early vessel was found off Padre Island near Port Mansfield, Texas. The wreck consisted of little more than the stern knee and a scatter of ship fittings, ground tackle, ordnance, and associated artifacts (Clausen and Arnold, 1976; Arnold and Weddle, 1978).

3.2.4 Remote Sensing in the Search for Historic Shipwreck Sites

In conducting surveys designed to identify historic shipwreck sites, a combination of acoustic and magnetic remote sensing instruments have proven to be the most effective. The array of instruments that represent the currently accepted standard for shipwreck remote-sensing survey operations include sidescan sonar, multibeam echo sounder, subbottom profiler, and magnetometer.

Sidescan sonar and multibeam echo sounders can be used to generate high-resolution digital images of shipwreck structure. Used in conjunction with highly sophisticated mosaicking programs, acoustic data from those instruments can be turned into highly detailed seafloor surface maps that illustrate wreckage scattered over broad areas. Magnetic data can be contoured to produce two- and three-dimensional images of anomalies associated with structural components and other material associated with the ship. Seafloor surface images and magnetic contour maps can be related on occasion to buried features using high-resolution subbottom profilers. Using GIS to store, analyze, and project those data can facilitate analysis and permit archaeologists and submerged cultural resource managers to identify shipwreck sites for research or protection.

4.0 STATE-OF-THE-ART REMOTE SENSING AND DATA ANALYTICAL TOOLS FOR SUBMERGED CULTURAL RESOURCE ASSESSMENT

Archaeologists have adopted a variety of geophysical remote-sensing instruments to locate and identify submerged cultural resources. The most useful instruments have proved to be magnetometers, sonars, subbottom profilers and, more recently, multibeam echo sounders. Operated in conjunction with a differential global positioning system (DGPS) and an onboard computer equipped with precision survey software, this array of instruments represent the currently accepted standard of remote-sensing survey operation. During the last decade, significant progress has been made in improving those survey systems.

4.1 Recent Technological Advances in Magnetometers

The most recent developments in magnetic remote sensing reflect a more precise means of measuring the earth’s magnetic field and refined means of collecting, storing, and presenting data. A number of important advances in remote-sensing survey operations reflect technology not available two decades ago. One of the most important developments is the shift from analog to digital data collection and storage, which has dramatically changed and significantly improved both magnetic and acoustic remote sensing. Magnetometers that reflected state-of-the-art technology two decades ago were virtually all proton precession instruments with paper recorder displays and analog data outputs.

Today, state-of-the-art magnetometers use cesium vapor or hydrogen to measure the magnetic field and virtually all have processing components in the sensor for high sensitivity and very low noise (Geometrics, 2003; Marine Magnetics, 2003). All utilize digital technology, even the low-end proton precession magnetometers that remain on the market (Geometrics, 2003). Both the cesium vapor and Overhauser sensor instruments are advertised to have much greater sensitivity than proton precession instruments (Marine Magnetics, 2003). Multiple sensor instruments have been developed to operate as gradiometers providing amplified data that include target direction, size, and distance (Geometrics, 2003; Marine Magnetics, 2003).

Although all of the new generation magnetometers can be connected via a computer to a printer, data are almost universally computer displayed in real time. Data display can be achieved by a computer dedicated to the magnetometer, or the magnetometer can be connected directly to the navigation computer for both real time display and data storage. Targets can be filed and represented on the navigation display by a keystroke. All of the magnetometers can be fitted with depth and/or height over bottom sensors to facilitate maintaining survey altitude requirements (Geometrics, 2003; Marine Magnetics, 2003).

4.2 Recent Technological Advances in Acoustic Instruments

Acoustic remote-sensing instruments utilize sound to measure depth, generate images of the seabed and material exposed on the bottom surface, and to define subbottom sediments (Mazel, 1985). Sound pulses generated by a transducer travel through the water column and are bounced back by the bottom surface, material exposed on the surface or subbottom sediments, and buried geological or cultural features. That echo is received by the same or a secondary transducer and processed according to amplitude and return time. The processed return signal generates lines of resolution that can be compiled to form a high-resolution image.

While the depth recorder or precision survey fathometer is perhaps the most elementary of the acoustic remote-sensing instruments, it can present an accurate profile of the water depth and bottom surface under the survey vessel. Highly sensitive survey depth recorders can provide insight into bottom surface sediments, surface geological features, and exposed cultural resources (Ocean Data Equipment Corporation, 2003; Kongsberg, 2003; Reson, 2003). Swath systems use dozens of variable frequency transducers to produce more detailed images of a wider bottom surface area. Multi-beam systems use a single or double transducer array that generates several hundred focused beams that cover a path much broader than swath systems. Data from swath and multi-beam systems can be processed to produce high-resolution images of the seabed and features or objects that are exposed on the bottom surface (Reson, 2003; Kongsberg, 2003; Triton Elics International, 2003). High-resolution sonars use sound focused into narrow horizontal beams and oriented perpendicular to the transducer to collect data along survey track lines. They still provide the most detailed images of the bottom surface features and exposed objects, but lack the high degree of geo-referenced accuracy that hull-mounted single and multi-beam systems can achieve (Klein Associates, Inc., 2003; Edge Tech, 2003; Benthos, Inc., 2003; Marine Sonics, 2003).

Digital technology has revolutionized acoustic remote-sensing. Sonar units manufactured two decades ago were all analog instruments. Unless complex magnetic tape data storage devises were employed, mechanical recorders producing paper records provided both the real-time visual display and data for storage. With options, most instruments are equipped to be connected to navigation systems for recording event marks and limited positioning data (Klein Associates, Inc., 2003; Edge Tech, 2003; Benthos Inc., 2003; Marine Sonics, 2003).

While most sidescan sonar systems are equipped to interface with recorders that generate paper records, they are designed to present and store data electronically. Virtually all sonar units available today operate on computer-based systems. Computer-based systems have advanced high-speed signal processing and most sensors are equipped with much improved transducers that provide better control over beam transmission and reception. In addition, computer-based systems are programmed to connect record processing with real world geographical coordinates permitting the computer to correct for speed and eliminate slant range error in real time by program functions. Computer-generated resolution is higher and tow speeds can be significantly increased. Most new systems are designed to operate at dual frequencies such as 100kHz/500 kHz (Klein Associates, Inc., 2003; Edge Tech, 2003; Benthos Inc., 2003).

All of those improvements contribute to higher resolution images. The higher the resolution of the sonar data, the more diagnostic the image. Sonar imaging of the remains of the Civil War blockade runners *Georgiana* and *Mary Bowers*, sunk off Charleston, South Carolina provides an indication of the level of detail that close range investigation can generate (Fig. 3). With digital systems, data can be extensively manipulated to improve image quality. High detail, seamless, georeferenced mosaics (Fig. 4) can be produced for entire survey areas (Klein Associates, Inc., 2003; Triton Elics International, 2003; Chesapeake Technology, 2003).

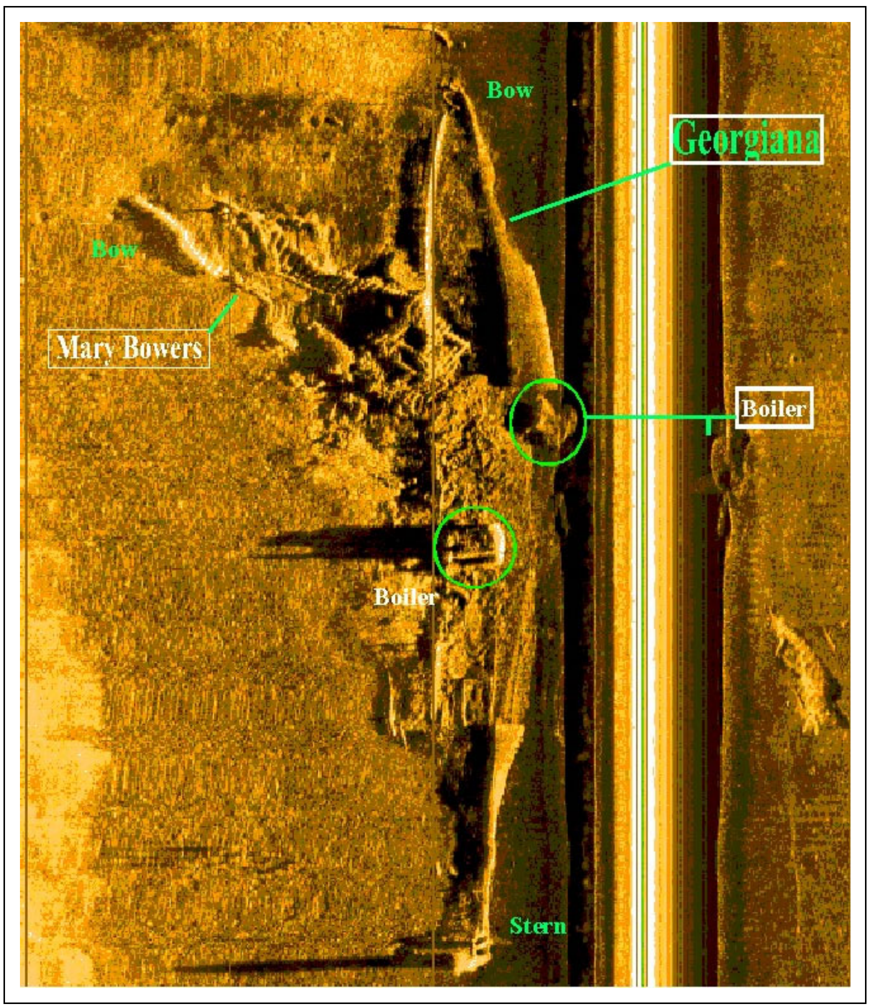

FIGURE 3. High-resolution Klein 500 kHz side scan sonar image of the Civil War blockade runners *Georgiana* and *Mary Bowers* sunk off Charleston, South Carolina (Image courtesy of Ralph Wilbanks, Diversified Wilbanks, Inc.).

Digital technology also has improved subbottom profilers. Like sidescan sonars, virtually all of today's high-resolution subbottom profilers operate on computer-based systems. Computer data processing has improved resolution greatly. Advances in the design of transducers have also contributed to improved stratigraphic definition. New transducers produce narrower beam widths with reduced side lobes and have a higher frequency range. Most produce a short sound pulse without ringing and have higher pulse rates. Many systems are compatible with heave, pitch, and roll compensators for much improved record detail. Positioning can be integrated with the data to facilitate feature location and three-dimensional projection. The primary result of these improvements is better stratigraphic definition (Kongsberg, 2003; Benthos Inc., 2003; Ocean Data Equipment Corporation, 2003). Preliminary experiments are currently underway to use non-linear acoustics to generate high-resolution, three-dimensional images of buried objects such as mines. Although far from a deployable system, the scientific trials have proven encouraging (Guyonic, 2003).

FIGURE 4. Mosaic of dredging scars compiled from high-resolution 600 kHz sonar images (Image courtesy of Marine Sonic Technology and Ocean Star Systems).

One of the most significant developments in acoustic remote-sensing technology during the last two decades is in the field of echo sounders. While single beam echo sounders or precision depth recorders have benefited from improvements in transducer design and computer-based technology, the major thrust in bottom surface mapping has been focused on multi-beam systems. Multibeam echo sounders use as many as several hundred dynamically focused beams generated by one or more transducers (Reson, 2003; Triton Elics International, 2003; Kongsberg, 2003).

The Reson Sea Bat 8125 Ultra High Resolution Multi-beam Echo Sounder was designed to utilize near-field focused beam forming to achieve high-resolution imaging. That instrument was used by Reson to conduct surveys of a number of WWII shipwrecks, tanks, and caissons sunk during the D-Day invasion at Normandy for the Naval Historical Center. Although the images lacked the clarity of a high-resolution sonar, the Sea Bat 8125 produced a three-dimensional image of both sunken vessels and the surrounding sea bed (Fig. 5). Data generated by the Sea Bat was tied to DGPS, and a motion sensor was used to minimize heave, roll, and pitch. Fledermaus visualization software was then used to enhance three-dimensional imaging of the Sea Bat 8125 data (New Waves, 2003). While the image resolution still leaves something to be desired, clearly multi-beam echo sounders can be of considerable assistance in imaging shipwrecks and their environment.

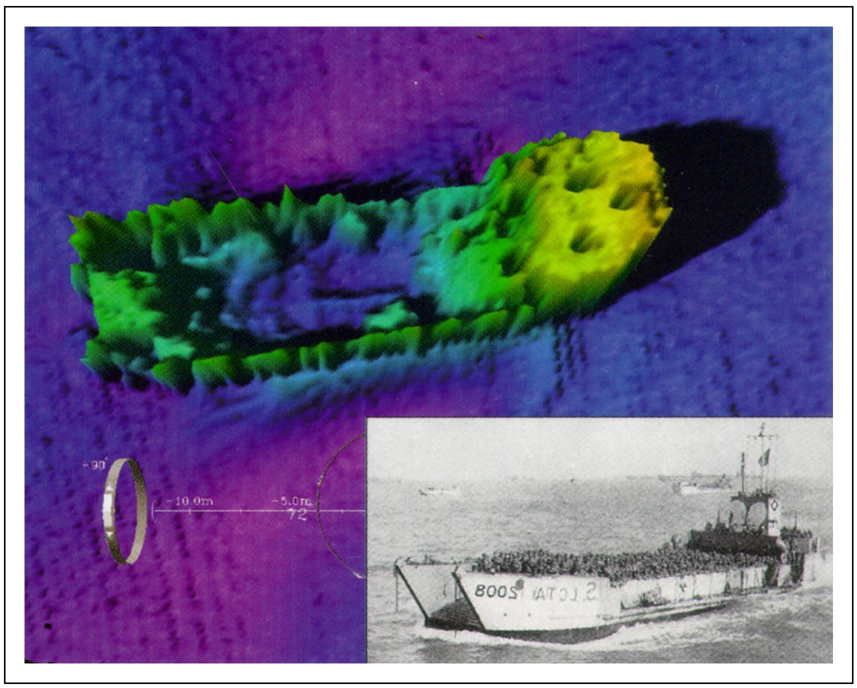

FIGURE 5. Reson Sea Bat 8125 image of a World War II LCT sunk off Omaha Beach, Normandy during the D-Day Landing (Image courtesy of Reson and the Naval Historical Center).

4.3 Global Positioning Systems

Two of the most important aspects of remote sensing are vessel positioning and data collection. Microwave ranging systems that were the industry standard several decades ago were quickly replaced by satellite navigation systems. Initially, differential stations were required to correct for "selective availability," errors intentionally programmed into the system to degrade positioning accuracy. With differential corrections, positioning accuracy of less than 3-5 m was possible. As more satellites were placed in orbit, better geometry was possible, and DGPS manufacturers expanded the number of satellite channels available for positioning. After the

United States government eliminated “selective availability” in 2002, positioning accuracy was enhanced by additional increases in the number of channels that could be used to calculate positioning geometry. Today global positioning systems are capable of generating highly accurate sub-meter positioning data. Using real-time kinematic (RTK) GPS, survey vessels can tie data to centimeter accurate three-dimensional positions (Trimble, 2003; Thales Navigation Solution, 2003), providing more accurate target positioning and more sophisticated data interpolation. Offshore distances greater than 20 km need a good radio link and RTK GPS base station.

4.4 Advanced Survey and Dredging Software and GIS Applications

The development of sophisticated survey software has been as important as improvements to remote-sensing equipment. In addition to providing real-time vessel and multiple sensor positioning, software programs collect and display magnetic and acoustic data. Survey software is designed to track the position of multiple sensors, significantly enhancing the geographical accuracy of data collection. Georeferenced data contouring and target identification can be accomplished using integral subroutines (Coastal Oceanographics, 2003). Sonar and multi-beam software packages permit data to be mosaicked to provide images of large anomalies and the seabed (Triton Elics International, 2003; Chesapeake Technology, 2003). Three-dimensional imaging of magnetic and acoustic data will become a more essential element of target identification and assessment in the future. Dredges are being equipped with navigation computers and dredging software that permit a high degree of three-dimensional control over excavations (Andrews, 2004; Knisley, 2004). Such level of control could facilitate preliminary testing of models for prehistoric site distribution on the OCS by sampling material associated with specific stratigraphic features.

Because of the speed and efficiency with which computerized data can be recovered, the use of GIS has grown rapidly during the 1990s. It is a principal tool to store, centralize, organize, update, and access the data necessary to facilitate effective management and decision making. Even archaeologists have broken through their traditional reluctance to embrace new technology and recognized the usefulness of GIS. Today, GIS applications are being developed to assist both submerged cultural resource managers and contract and research archaeologists in effectively storing, organizing, and analyzing data (Watts and Mather, 1998; Mather and Watts, 2002).

One of the most controversial uses of GIS in archaeology has been in predictive modeling. Many of those who see predictive modeling as an important tool also recognize GIS as the ideal instrument for conducting their research. Digital databases can be used to overlay known sites with multiple environmental variables to develop statistical models of environmental conditions around the site that can then be applied elsewhere (Mather and Watts, 2002).

The capacity and analytical capability of GIS encourages researchers, whether they are interested in predictive modeling, archaeological sensitivity analysis, site-specific investigations, management issues, or survey, to gather substantial amounts of data and then display, analyze, and explore that information. The graphic and visual representations of thematic maps and overlays often show relationships between data sets with startling clarity. This form of exploratory inductive research is commonly referred to as exploratory data analysis (EDA) and stands in contrast to the more hypothesis-driven deductive research with which most archaeologists are primarily familiar. As underwater archaeologists adopt GIS, they might consider adopting EDA to explore their data and the relationships between variables in this way. It may then become possible to develop more fruitful hypotheses and theories, which can be tested by augmenting the same GIS with additional data sets (Mather and Watts, 2002).

GIS is already proving to be valuable management tools for both cultural resource managers and site-specific investigations. The systems are being used to preserve, store, display, and analyze multivariate spatial data sets and to access instantaneously information which was hitherto often difficult or cumbersome to acquire. It is now possible to use GIS to gather real-time data from a typical underwater archaeological remote sensing survey, and it may be possible to develop complex GIS-based predictive models for shipwreck losses (Mather and Watts, 2002).

5.0 DREDGING IMPACTS ON SUBMERGED CULTURAL RESOURCES

Dredging impacts on submerged cultural resources can be classified as direct and indirect. Direct impacts are associated with damage caused by the dredging equipment itself. While the most destructive impacts are normally related to cutterhead or draghead damage, submerged cultural resources can be adversely impacted by ground tackle associated with mooring or maneuvering the dredge. Indirect impacts are associated with exposure or burial of submerged cultural resources. Burial from sedimentation on top of the resource could have both positive and negative impacts. Although archaeologists and submerged cultural resource managers generally agree that sedimentation affords protection for underwater archaeological sites, little attention has been directed to the issue. An examination of the condition of deeply buried vessels associated with this study indicates that burial does in fact facilitate preservation by isolating the site from environmental dynamics such as erosion. Where sites are exposed to environmental dynamics, the adverse impacts are readily apparent. Perhaps the most obvious adverse impact of inadvertent (collateral) sedimentation associated with dredging is making scientific examination of the site more difficult by limiting direct access. Sedimentation could also impact public access, however, on historically significant and fragile resources that would not necessarily be an adverse impact. Models for assessing the effects of inadvertent sedimentation associated with dredging indicate that the impacts would be marginal (see Appendix C).

5.1 Direct Impacts of Dredging

The literature survey associated with dredge activity and submerged cultural resources identified 20 documented cases where dredging damaged shipwreck remains (Table 4). In some cases, like the *Fame* in Sydney Harbor, Australia (Nutley, 1999), the bronze howitzer wreck in Pensacola, Florida (Franklin et al., 1992) and the *Le Juste* in the Loire River in France (Blot, 1998), entire wrecks appear to have been destroyed. In less extreme cases, like the Averio Harbor wreck in Portugal (Alves, 1998; Blot, 2002) (Fig. 6) or the SS *Mary* in the Houston Ship Channel (Pearson and Simmons, 1995) (Fig. 7), dredging has not destroyed the entire wreck and has resulted in archaeological investigation of the surviving remains. Some highly valuable sites like the Bremen cog (Pedersen, 1972) have been exposed by dredging and have been recovered and preserved virtually intact. Most of the documented dredge-related impacts to submerged cultural resources have been associated with developing and maintaining navigation channels. However, as the demand for sand increases, dredge damage has become a more common occurrence in coastal, inlet, and offshore areas.

Many dredge operations, particularly those employing cutter head dredges, require heavy ground tackle to control dredge and pipeline positioning. Anchors are frequently set well outside the area to be dredged and outside the area that has been surveyed. The destructive impact of anchors can be seen in the remains of the ironclad CSS *North Carolina*. A 15,000 pound stockless navy anchor was dropped on the bow of the *North Carolina* in 1995 to serve as a mooring for barges carrying dredging equipment. An investigation of the wreck in 1997 documented the extent of damage (Fig. 8) caused by placing the anchor inside the historic ship's bow and pulling it back out through the hull (Watts, 1999).

Adverse impacts can also be caused by the wire and chain used on ground tackle. Although the following examples are not a result of dredging activities, they represent the types of damage that can occur from ground tackle. Wire found in association with a section of the armored casemate of the CSS *Georgia* indicates that a section of the structure was broken off by wire associated with barges anchoring in the area where dredging is not permitted. While the scenario cannot be reconstructed, it is apparent that the wire was responsible for the damage. Another example can be found in the Hilton Wreck, a small mid-nineteenth century schooner lost in the Northeast Cape Fear River at Wilmington, North Carolina. The Hilton Wreck was found virtually intact in 1988 during a remote-sensing survey for the Wilmington District Army Corps of Engineers (Fig. 9A). During the spring of 1989, an ocean-going tug towing a barge with a wire bridle dragging from the stern passed the site (Fig. 9B). The bridle fouled a telephone cable and pulled it across the stern of the Hilton Wreck, destroying most of the transom, part of the cockpit, and virtually all of the deck aft of the cockpit (Watts, 1994).

In Savannah, Georgia, the remains of a number of vessels have been discovered and documented on Fig Island. Their remains were partially exposed in the intertidal zone by dredging associated with maintenance and improvement of the Savannah River Navigation Channel (Fig. 10). Following additional exposure during the documentation process, the vessels deteriorated rapidly as a consequence of continued erosion, strong currents, and vessel wakes. In some cases, the entire hull structure disappeared.

The deposition of additional material on submerged cultural resources has been identified as a potential consequence of dredging operations. While there is little direct evidence to measure the impact of increasing sediment over a site, archaeological evidence associated with deeply buried shipwrecks indicates the impacts are marginal. In fact, the available evidence suggests that burial enhances preservation of both the wreck structure and the associated archaeological record. Where sediments burying the wreck are stable and anoxic, vessel remains have survived thousands of years (Bass, 1988). Table 5 lists some examples of deeply buried shipwrecks where burial was thought to be a factor in the survival of the remains.

TABLE 4. Documented cases where dredging activities damaged shipwreck resources.

Location	Date	Wreck Date	Name	Vessel Type	Event Type	Info. Source
Aransas Pass, TX	1890 to Date	1876	*Mary*	Morgan Line Steamer	Jetty Construction	Texas Historical Commission
Mansfield Channel, TX	1950s	1554	*Santa Maria de Yciar*	Spanish Galleon	Port Dredging	Texas Historical Commission
Loire River, France	1960's	1759	*Le Juste*	70-gun Warship	Maintenance Dredging	NUA/Blot (1998)
Oostvoornse, Holland	1960's	1735			Sand Mining	Maarleveld (1993)
Bremen, Germany	1962	1350-1400	Unknown	Cog	Port Dredging	Pedersen (1972)
Savannah River, GA	1968	1864	CSS *Georgia*	Civil War Ironclad	Maintenance Dredging	USACE Savannah (2002)
Trinity River, TX	1970s	1869	*JD Hinde*	Shallow Water Steamer	Channel Dredging	Texas Historical Commission
Arade River, Portugal	1970	1500s		Several Vessels	Harbor Dredging	Alves et al. (2001)
Lockwoods Folly Inlet, NC	1985	1863	USS *Iron Age*	Union Gunboat	Channel Dredging	Watts (1986)
Pensacola, FL	1990	1850	Brodie's Wharf	Caisson	Harbor Dredging	Franklin et al. (1992)
Pensacola, FL	1990	18^{th} Century	Unknown	Unknown	Harbor Dredging	Franklin et al. (1992)
Parnu River, Estonia	1990	1300s		Medieval Cargo Vessel	Bank Dredging	Mass (1999)
Sydney, Australia	1991	1857	*Fame*	Coal Ship	Maintenance Dredging	Heritage Office NSW (2003)
Lynnhaven, VA	1994	19^{th} Century	Unknown	Unknown	Channel Dredging	Watts (1995)
Southport, NC	1995	1864	CSS *North Carolina*	Ironclad	Ground Tackle	Watts (1999)
Jupiter Inlet, FL	1995	1659	*San Miguel Archangel*	Correspondence	Sand Mining	Amelia Research and Recovery (2002)
Aveiro, Portugal	1994	1450s		Coastal Trader	Harbor Dredging	CNANS
Belmar, NJ	1997	19^{th} Century	Belmar Wreck	Merchant Vessel	Sand Mining	NJ Historical Divers Assoc.
Belmar, NJ	1997	19^{th} Century	Green Hull Wreck	Merchant Vessel	Sand Mining	NJ Historical Divers Assoc.
Charleston, SC	2000	1865	Unknown	Confederate Ironclad	Harbor Dredging	Tuttle (2000)

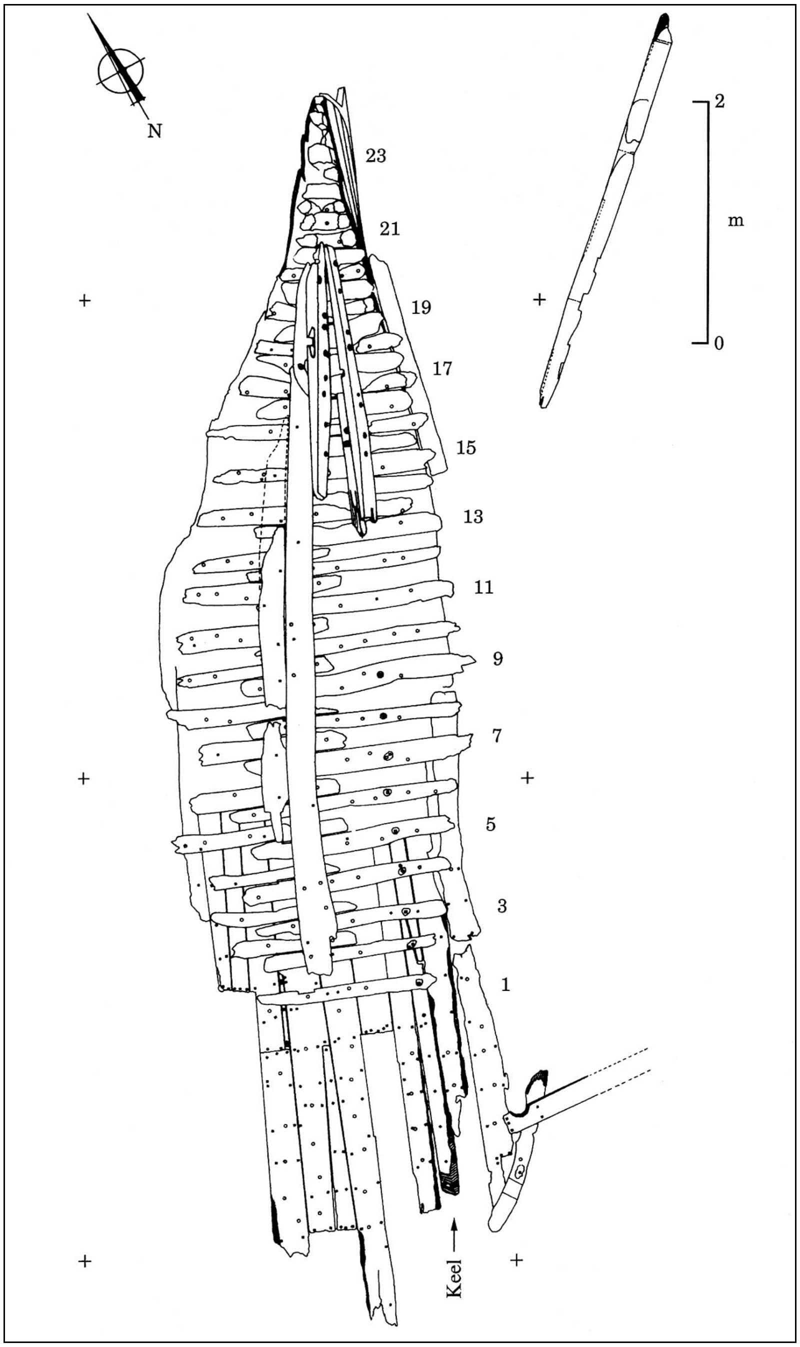

FIGURE 6. Plan of the surviving remains of the mid-fifteenth century shipwreck discovered during dredging of the Ria de Averio, Portugal (Site plan courtesy of Miguel Aleluia).

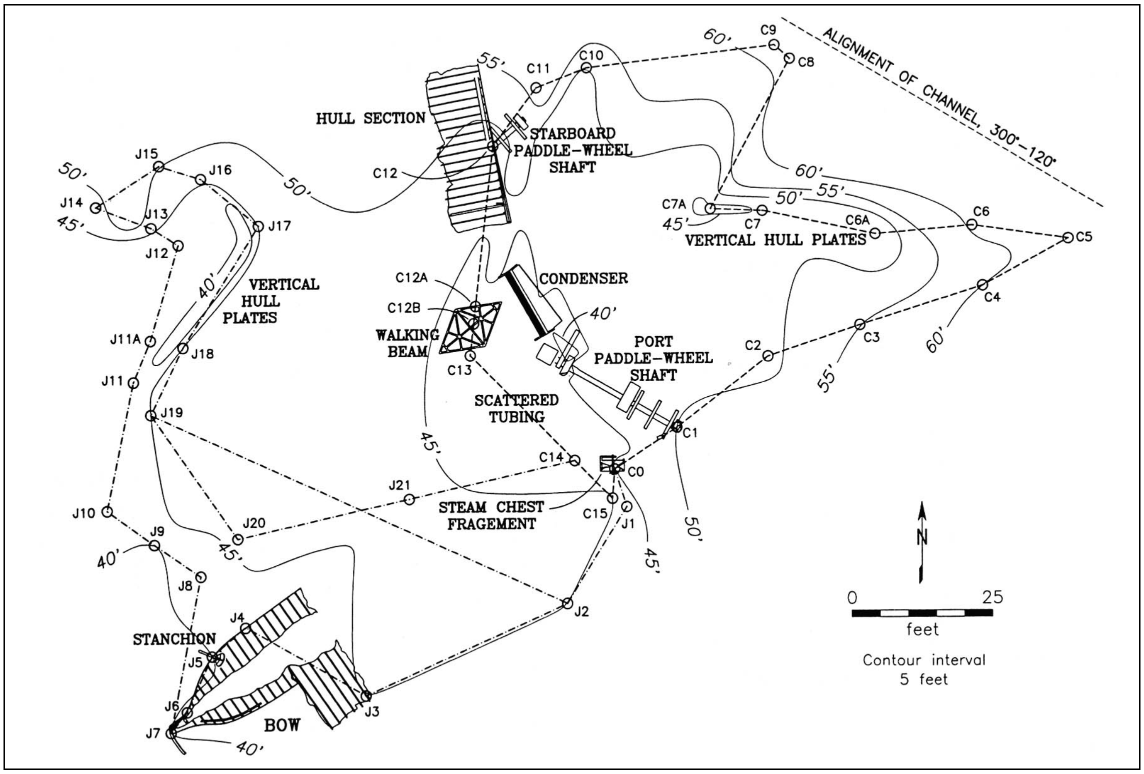

FIGURE 7. Plan of the surviving remains of steamship *Mary* sunk adjacent to the Aransas Pass, Texas navigation channel (Image courtesy of Coastal Environments, Inc., 1977).

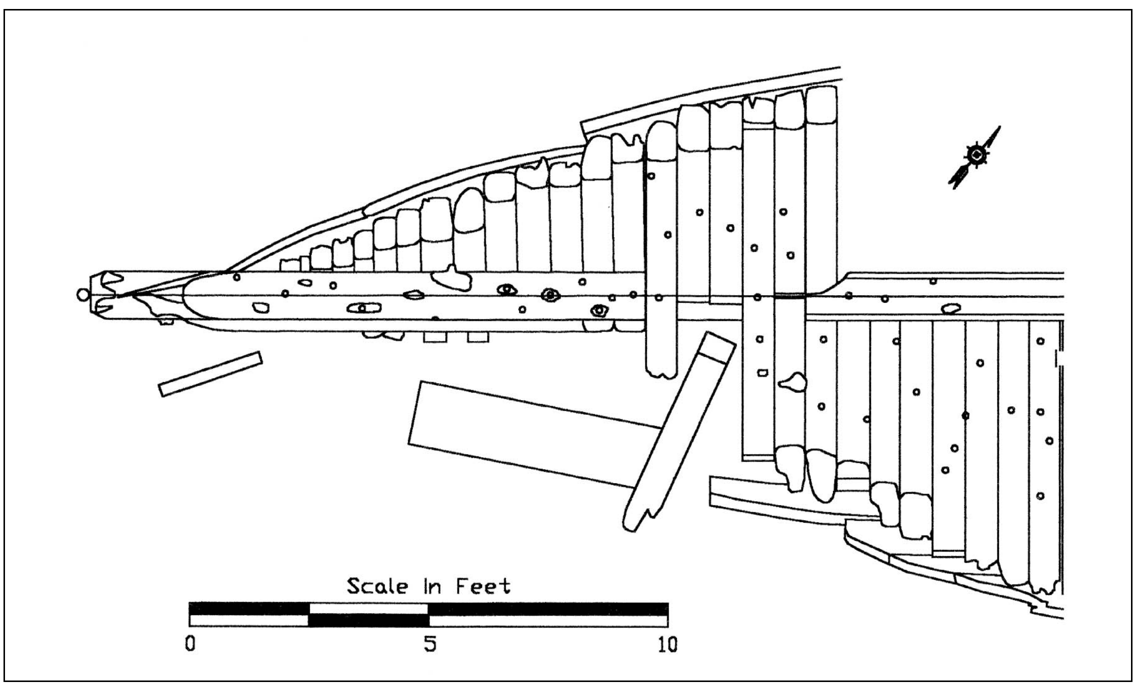

FIGURE 8. Plan of the bow of the ironclad *CSS North Carolina* illustrating the damage done by anchoring in the wreck (Image courtesy of Tidewater Atlantic Research, Inc.).

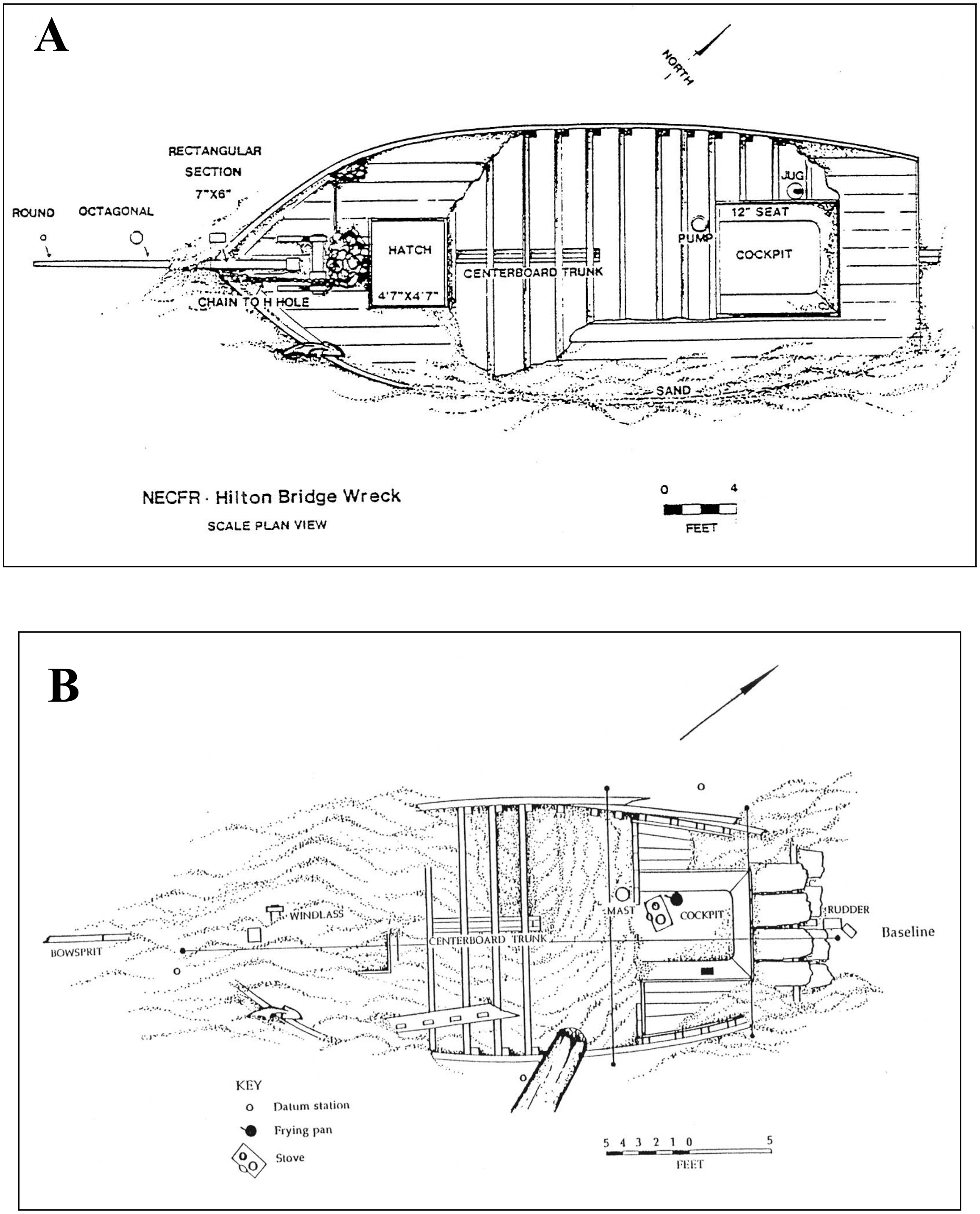

FIGURE 9. Illustration of the remains of the mid-nineteenth century Hilton Wreck schooner (A) prior to damage by dragging a cable across the hull and (B) after dragging a cable across the hull (Watts, 1994).

FIGURE 10. Photograph of work on Fig Island Vessel #2 during documentation of the wreck for the Savannah District USACE (Photograph courtesy of Judy Wood).

TABLE 5. Examples of deeply buried shipwrecks.

Vessel Location	Date of Investigation	Wreck Date	Name	Vessel Type	Depth of Overburden	Info. Source
Relic Channel Missouri River	1969	1865	*Bertrand*	River Steamer	30 feet	Petsche (1974)
Relic Channel Missouri River	1987	1856	Arabia	River Steamer	45 feet	Hawley (1998)
New York, NY	1980	18^{th} Century	Unknown	Unknown	20 feet	Rosloff (1986)
Portsmouth, VA	1989	18^{th} Century	Unknown	Unknown	Harbor Dredging	Watts (1998)
San Francisco, CA	1994	1852	Rome	Ship	40 feet	Allan et al. (1995)
Newport, Wales	2002	15^{th} Century	Unknown	Unknown	20 feet	BBC News (2002)

6.0 DREDGING INDUSTRY SURVEY RESULTS

6.1 Current Dredging Practices: Equipment

Dredging industry publications were reviewed and a list of the largest dredging companies in the world was determined (*World Dredging Mining & Construction*, 2002). The companies were selected by the number of dredges owned that would be capable of mining sand in the typical borrow area as described in Table 1. Forty-four companies were selected. These companies are primarily located in North America, Western Europe, and Southeast Asia. A list of questions was developed to determine the operational parameters used by the dredging industry with particular attention to type of dredge and accuracy of determining the position of the dredge (see Appendix A). The industry responses came from companies based in Western Europe and North America. No responses were received from companies located in Southeast Asia, which may be due to language barriers or the exclusion of these companies from the United States market. This lack of response will not degrade the information in the study because the responding companies from Western Europe and North America are the leaders in the dredging industry who are working worldwide, including Southeast Asia.

The industry responses showed a clear preference for the use of trailing suction head dredges to mine sand from the typical borrow area (see Appendix D). The hopper dredge is essentially a ship with dredging, propulsion, and navigation equipment on board. The dredge has a large cargo bin or hopper. The dredge removes sand from the ocean floor by pumping through a drag arm and deposits the sand in the dredge hopper for transport to the beach. Typically, the dredge pumps the sand in its hopper directly onto the beach. In limited circumstances, a Cutterhead Suction or Plain Suction dredge may be used. The Cutter Suction loading barges may be used if the borrow area is in shallow water. The Plain Suction may be used if the borrow deposit is very deep. The industry response to potential future upgrades of equipment would be to use larger equipment. Some of the hopper dredges being used on large land-reclamation projects in Southeast Asia are ten times larger than the typical hopper dredge used on beach-fill projects in the United States. The industry is also working on reducing the adverse effects of the dredging process on the environment, primarily by reducing turbidity.

6.2 Current Dredging Practices: Location of the Dredge Position

Each dredging company that responded to the Dredging Industry Survey stated they used DGPS to determine the location of the dredge. DGPS is a system that utilizes satellites to determine position on Earth. The system consists of 24 satellites and ground stations. A DGPS receiver uses a minimum of three of these satellites to locate position by triangulation. The system utilizes a fourth satellite to determine a unique solution to its location. This system is very accurate. There are, however, small inaccuracies due to the variable nature of the speed of light through different mediums. To increase the accuracy of the system, a stationary ground position is located very accurately. The stationary position is very close to the satellite ground stations relative to the distance to the satellite. Essentially, the distance from both ground stations to the satellite is the same. Utilizing the known position of the stationary ground position, it is possible to work backwards and make a timing (and distance) correction to the satellites. This process allows the DGPS system to determine location to an accuracy of 3-6 m (www.trimble.com). DGPS systems give position in latitude/longitude and some receivers can also give position in local grid, simultaneously. Vertical position can be determined to sub-meter accuracy utilizing pressure sensors and real time tide data (Chisholm, 2003).

Dredge location to DGPS accuracy should be more than sufficient to maintain systems to protect submerged structures. If greater accuracy should be required, a real-time kinematics (RTK) receiver can be added to the system. Under these conditions, the position accuracy would be less than 1m (Chisholm, 1999a; b; 2001). Offshore distances greater than 20 km need a good radio link and RTK base station.

The Dredging Industry Survey did not specifically request information on Dredge Tracking Systems. There is, however, technology available that can continuously track and record the location of a dredge and its draft (Pace and McDowell, 1998). Thus, dredging companies have sufficient technology to determine the location of the dredges within the accuracy required to devise a system to protect the submerged archaeological and historic sites. Furthermore, it is now possible to record the actual dredge tracks relative to any exclusionary zones for submittal by the dredge contractor as part of the monitoring requirements of the project.

6.3 Current Dredging Practices: Buffer Zones

One measure to prevent damage to shipwrecks or other relevant archaeological sites is to set an area around the target at which no dredging or anchoring may occur, referred to as a buffer zone. The worldwide literature search produced information about buffer zones. Different countries, and states within the U.S., have different measures and standards for setting buffer zone areas around archaeological sites. In Australia (Nutley, 2003) and the UK (Oxley and O'Regan, 2001), a 450 m buffer is commonly used while in the U.S. buffer widths vary from 30 m to 360 m.

For maintenance dredging operations in inland waters where buffer size restrictions depend on channel width, relatively narrow buffer zones may have to be set. In the Trinity River in Texas, a wreck protruding from a bank has been damaged by dredging operations (Hoyt, 2003). Recently, a buffer zone of 20 m was set for maintenance dredging around this wreck, which is the largest buffer that can be set for this particular location due to river-width limitations. In Savannah Harbor where the CSS *Georgia* lies, the buffer zone has been 30 m by 300 m for the last 20 years and was recently expanded to 150 m by 600 m (Wood, 2003).

The process of establishing open coast buffer areas is based upon negotiations between the SHPO and the USACE depending on the dispersion and historical value of the wreck. A sand mining project near Hereford Inlet in New Jersey has set buffer areas of 60, 90, 150 and 360 m (DACW61-B-02-0001) whereas the USACE - Mobile District uses a buffer larger than 90 m (Gibbens, 2003). The New Jersey 1997 incident (Table 4) used a buffer zone of approximately 45 m (30-60 m depending on the information source) (Fullmer, 2002). The USACE – New York District recommends using 230 m buffer zones for future sand mining projects (Panamerican Consultants, Inc., 2001). After the Dredge Long Island incident in the New Jersey borrow area, the USACE – New York District negotiated with the New Jersey SHPO to set the buffer zone at 230 m. John Killeen (2003), Project Archaeologist for the USACE – New York District said they are in the process of reviewing their buffer zone policy.

In the Dredging Industry Survey, the companies were asked about buffer or exclusion zones. Most of the companies had experience with these zones. Exclusion zones have been used around "hard-bottom sites" (coral reef sites) for many years. In answer to a question on the appropriate width for a buffer zone next to an archeological resource, the dredging contractors suggestions ranged between 15 and 500 m. The recommendations averaged approximately 150 m between the edge of the location of the resource and the dredge limit line. They also suggested that the dimensions of the zones should be set after a review of the site conditions. Some wrecks are spread out in debris fields as opposed to being single point locations. The size of the borrow area will also influence the dimensions of a buffer zone, as will the confidence of the location of the resource.

The site-specific review should also consider the possibility of erosion around the site after the borrow operation has been completed. It may be helpful to utilize scour, vessel movement, wave dynamics, numerical modeling, and visualization tools to determine an optimum size and shape for the buffer zone. Visualization of a borrow area after one or more dredging operations around buffer zones may be particularly helpful in avoiding the development of pedestal conditions (see below). A typical zone of approximately 150 m may be selected to cover weather, temporary power failure, loss of communications, and similar interruptions to the normal dredging process. This zone is an arbitrary starting point based on the Contractor's experience and recommendations. Each resource site should be investigated and the buffer zone determined as stated in the recommendations.

7.0 ARCHAEOLOGICAL RESOURCE SURVEY REQUIREMENTS

7.1 Current MMS Requirements for Gulf of Mexico Archaeological Resource Surveys

To ensure that dredging associated with the removal of sand from borrow areas on the continental shelf does not disturb or destroy prehistoric and shipwreck resources, MMS has commissioned a review of their existing remote-sensing survey requirements. Those requirements for the Gulf of Mexico Region were identified in the Notice to Lessees 98-06 (MMS, 1998) and revised in Notice to Lessees 2002-G01 on 15 March 2002 (MMS, 2002). MMS regulations for archaeological resource field surveys identified in that document were developed to identify and protect submerged cultural resources in lease areas where oil, gas, and sulfur deposits are being exploited. MMS guidelines for the conduct of archaeological resource remote-sensing surveys address three basic issues: survey navigation, survey pattern, and data acquisition instrumentation (Notice to Lessees 2002-G01). No requirements have been adopted for the Atlantic OCS and slightly different requirements are in place for the Pacific coast (Notice to Lessees 98-05).

Survey navigation parameters identify equipment capabilities and positioning data requirements. In water depths less than 200 m, navigation system geographical accuracy must be ± 5 m. Position fixes must be logged digitally at a minimum of every 12.5 m along each data acquisition track line. All related remote-sensing records must be annotated with geographical fixes at intervals not exceeding 152 m (Notice to Lessees 2002-G01). The shallow water requirements for surveys in less than 200 m apply to all areas MMS has identified as potential sources of sand.

Survey pattern requirements define the line spacing for remote-sensing data collection. In shallow lease blocks, less than 200 m, that have been identified as having potential for shipwreck or prehistoric resources, line spacing must not exceed 50 m (Notice to Lessees 2002-G01). The line spacing for lease blocks having potential for prehistoric submerged cultural resources is 300 m (Notice to Lessees 2002-G01). Those requirements will apply to all of the areas MMS has identified as potential sources of sand. As 50 m has been identified as the maximum line spacing in the Gulf of Mexico in lease blocks in less than 200m of water, it has by default also become the minimum as survey expense increases where line spacing decreases. Off the Pacific coast, typical line spacing in areas that are highly likely to contain historic sites is 40 m and where historic sites are less likely the line spacing is 150 m. Line spacing for surveys for prehistoric resources is 300 m (Notice to Lessees 98-05).

Data acquisition instrumentation identifies the geophysical instruments and capacities that are acceptable for conducting archaeological resource remote-sensing surveys. That array includes both magnetic and acoustic remote-sensing equipment (Notice to Lessees 2002-G01). In less than 200 m of water, the magnetometer is to be towed no more than 6 m above the bottom surface. Sensor depth is to be controlled by a mechanical or digital depth recorder and start of line (SOL) and end of line (EOL) depths are to be recorded. Instruments are to be set for one gamma, or one nanosecond Tesla sensitivity or less, and the sample rate is to be one, or less than one, reading per second. Digital and strip chart records are to be recorded on dual scales set no greater 100 gammas and 1,000 gammas. Data collected on each line are be annotated with shot points and recorder speed, and the strip chart recorder is to be set at a speed of approximately two inches per minute. Background noise cannot exceed three gammas peak to peak (Notice to Lessees 2002-G01).

Where surveys are carried out in less than 200 m of water, or at line spacing of 50 m, a 300-500 kHz sonar is required. A 100 kHz or greater system may be used where 300 m line spacing is acceptable. Survey line spacing and instrument range setting are to be coordinated to ensure 100% coverage of the survey area. The sonar sensor is to be towed at a height above the bottom surface that reflects 10% to 20% of the range required to achieve 100% coverage. Sonar data is to be recorded both graphically and digitally and corrected for slant range and speed. Sonar data mosaics are required for pipeline surveys (Notice to Lessees 2002-G01).

Sub-bottom profilers are to employ frequencies between 1.5 kHz and 4.5 kHz. They are to be capable of resolving the upper 15 m of sediment (below mud line) with a vertical bed separation of at least 0.3 m. The instrument is to provide continuous very high-resolution detail, and data are to be recorded digitally for post processing (Notice to Lessees 2002-G01).

Bathymetric data are to be collected using a hull-mounted narrow beam hydrographic echo sounder. Date information is to be continuously recorded both graphically and digitally. The instrument is to be set to record with a sweep appropriate to the range of water depths in the survey area and calibrated using a conductivity temperature depth sensor or sound velocity probe. A heave compensator is to be used to correct for surface motion (Notice to Lessees 2002-G01).

7.2 Assessment of Current MMS Standards for Archaeological Resource Surveys

Today the MMS remote-sensing survey methodology and instrument requirements identified in conjunction with oil, gas and sulfur exploration and utilization are also employed for identifying submerged cultural resources in offshore borrow areas where sand will be dredged for beach nourishment projects. Given the potential for prehistoric and historic submerged cultural resources in continental shelf sand borrow areas, MMS is reconsidering those requirements. In addition, MMS is examining new and improved technology to identify the state-of-the-art survey methods and instrumentation that can be employed to reliably identify submerged cultural resources in sand borrow areas.

7.2.1 Archaeological Resource Survey Navigation

Positioning for marine surveys is much improved over the last two decades. The navigation system geographical accuracy of ± 5 m identified in the current MMS requirements for Archaeological Resource Surveys is well below current state-of-the-art capability. A number of companies offer marine survey DGPS for hydrographic surveys, rig or surface support vessel positioning, or dredging that provide three-dimensional centimeter accuracy positioning in real-time kinematics (RTK). Sub-meter, two-dimensional positioning accuracy in real time is readily accessible and no longer inordinately expensive. This increased accuracy permits much higher survey resolution, target definition, and precise anomaly location (Thales Navigation Solution, 2003; Trimble, 2003; Magellan Systems Corporation, 2003).

RTK is the process of transmitting GPS signal corrections from a reference station. An RTK-equipped GPS system can compensate for errors introduced by orbital variations, atmospheric delays, and variables in positioning geometry. Using both the code and carrier phase signals provides the differential corrections necessary to produce the most precise positioning accuracy. Use of RTK signal correction can significantly enhance positioning accuracy to within 1 centimeter (cm) (Trimble, 2003; Magellan Systems Corporation, 2003), under ideal conditions.

One significant improvement in navigation and survey positioning has been in the development of survey software and acoustic positioning systems that track towed sensor position. In deep water this issue is critical for accurate georeferencing of data. Towed sensors can be fitted with transceivers and be accurately tracked by short baseline positioning systems onboard the survey vessel. Autonomous underwater vehicles have been developed to conduct deep-water survey operations with a high degree of acoustic positioning accuracy. However, as beach nourishment sand sources are in relatively shallow water, more complex deep-water positioning systems are not generally necessary.

7.2.2 Survey Patterns: Impacts on Range and Resolution of Acoustic Imaging

Current line spacing for remote-sensing data collection in shallow lease blocks or that have been identified as having potential for shipwreck resources must not exceed 50 m. Line spacing for remote-sensing data collection in lease blocks or that have been identified as having potential for prehistoric resources must not exceed 300 m. As MMS has identified 50 m as the maximum line spacing for areas with shipwreck potential, it has by default become the minimum. Likewise, in areas with prehistoric potential, the 300 m line spacing has become the minimum. Line spacing is critical in generating data to support evaluation of both acoustic and magnetic anomalies. The closer the line spacing, the more data there are for analysis and interpretation. This issue is clearly one, if not the most important, consideration in the conduct of remote-sensing surveys for submerged cultural resources.

In a MMS study by Texas A&M University, the issue of line spacing was given consideration (Garrison et al., 1989). Regardless of whether magnetic or acoustic data are being analyzed, increased data means higher anomaly characteristic definition. With 50 m line spacing and a sonar range scale set to provide 100% or better coverage, a target is going to be less well defined than that same target imaged using a lower range scale but still providing 100% or better coverage. The lower the range setting, the faster the ping rate and the higher the resolution. The higher the resolution, the more diagnostic the image (Mazel, 1985; Marine Sonic, 1998).

While this issue is less of a concern with larger and well-defined targets, it can be of critical importance in the identification and analysis of smaller and more disarticulated vessel remains or other bottom surface features. Small, less well-defined objects on the surface of the seabed at the periphery of sonar range are more likely to be identified at a lower range scale than at a high one (Marine Sonic Technology, 1998). At a 50 m line spacing, a 30 m range scale might be necessary to obtain the required 100% coverage. At a 30 m line spacing, a 20 m range scale would be more than sufficient. The higher ping rate at 20 m would produce a higher resolution image with better object definition at the periphery. In shifting from a 50 m to a 25 m range scale, the ping or pulse rate doubles (Mazel, 1985).

Sonar target definition also is a factor of experimentation with scale, gain, vessel speed, stabile course, and direction across the target. Highly detailed and diagnostic images are generated rarely by a line-specific pass. Thus, in addition to considering a closer line spacing, MMS should consider requiring that all anomalies recommended for additional investigation or avoidance be afforded a more detailed inspection. Two examples of the increased resolution from closer line spacing are discussed below.

Using a Klein 3000 at a 50 m range scale the wreck of the CSS *Georgia* appears as a target at 75 m but lacks sufficient definition to contribute significantly to diagnostic analysis of the signature. Using the same range and data from a line run within 25 m of the wreck, the image is dramatically different. It is highly detailed and provides considerable insight into the nature and scope of material on the bottom surface (Figs. 11A and B).

A

B

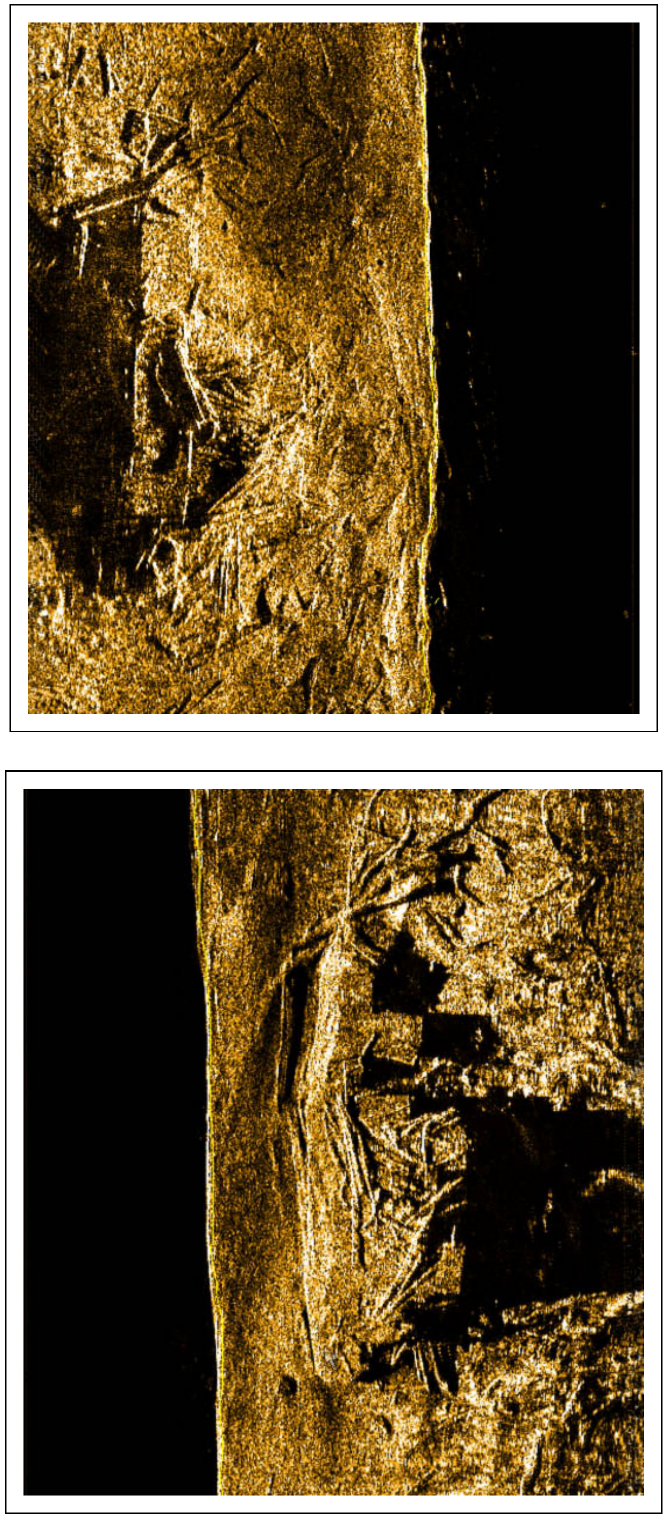

FIGURE 11. Klein 3000 image of the remains of the ironclad CSS *Georgia* recorded at a distance of 75 m (A) and at a distance of 25 m (B) (Image courtesy of Georgia Department of Natural Resources).

An image of the USS *Susan B. Anthony*, sunk off Omaha Beach, Normandy illustrates the relationship between resolution and the number of data points generated by sonar pings (Fig. 12). Each point on the image represents the return from one of several hundred beams in a SeaBat 8125 Multibeam Echosounder transducer. The closer the data points, the higher the image resolution. Consequently, the closer the target the higher, the level of diagnostic detail.

Sub-bottom profilers collect data along the vessel track. The analytical potential of data generated by those instruments also is relative to line spacing. Decreasing the line spacing increases the likelihood of identifying and characterizing both localized features such as relic landforms, shell middens, or buried non-magnetic shipwreck remains. To effectively characterize a localized buried geological feature or wreck using a sub-bottom profiler would require an exercise similar to that employed to generate a high-resolution sonar image. Additional lines run across all anomalies recommended for additional investigation or avoidance would generate more diagnostic data.

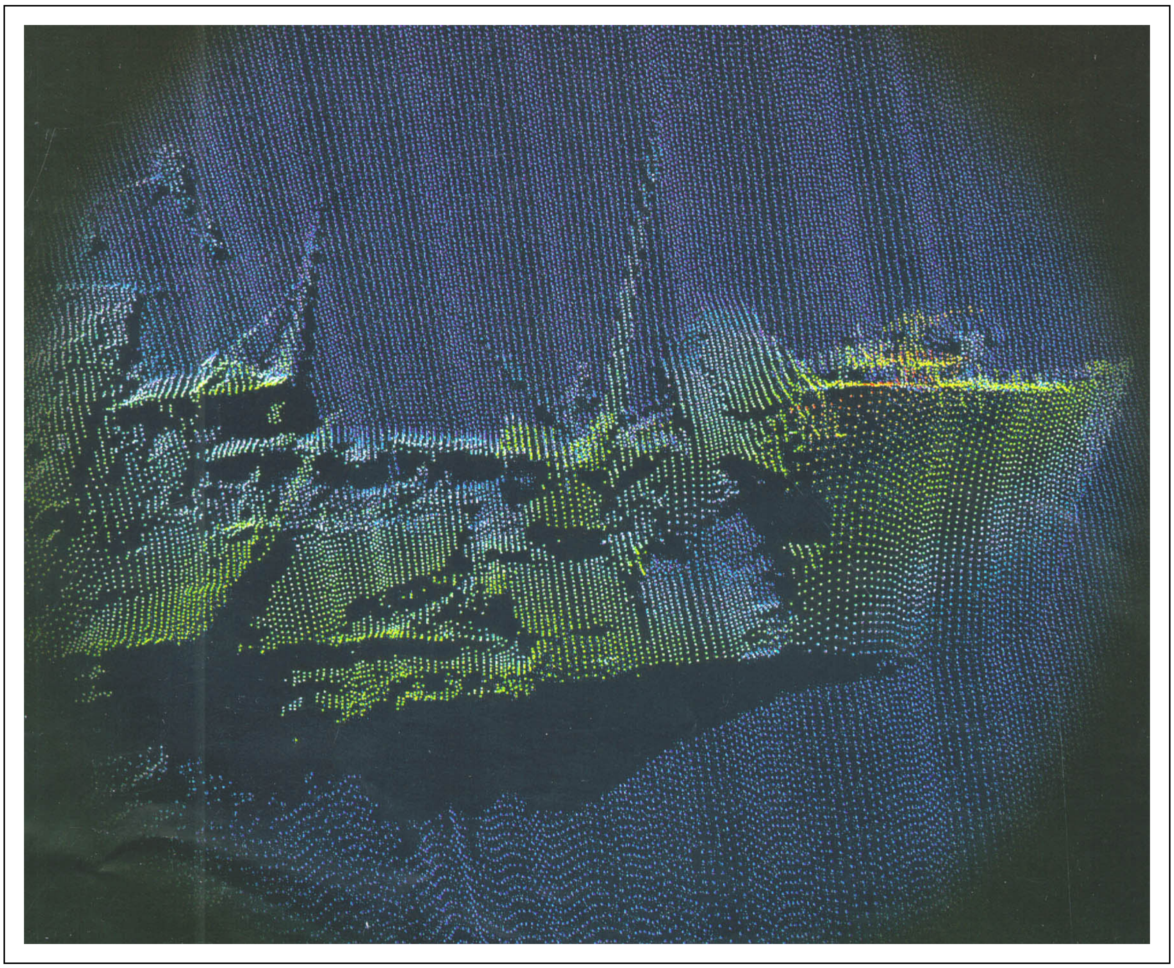

FIGURE 12. Reson Sea Bat 8125 data point image of the *Susan B Anthony* sunk off Omaha Beach, Normandy during the D-Day Landing (Image courtesy of Reson and the Naval Historical Center).

Subbottom profilers may provide the most useful data for identifying the relic landforms that are considered to be associated with submerged prehistoric sites. The current MMS line spacing does not generate sufficient data to identify accurately relic landforms or support detailed three-dimensional reconstruction of relic landforms such as river channels, bays, lagoons, levees, and barrier islands that could be associated with submerged prehistoric sites. Neither does it permit a clear association between sand deposits and relic landforms to be developed (Coastal Planning & Engineering, Inc., 2001; 2003). That relationship is clearly necessary if the impacts of dredging sand deposits are going to be identified. A comparison of channel reconstruction at the Holly Beach site at a line spacing of 300 m versus 50 m illustrates this point (Fig. 2).

7.2.3 Survey Patterns: Impacts on Range and Resolution in Magnetic Imaging

Diagnostic magnetometer data are equally range sensitive. In general, the intensity of an anomaly decreases geometrically as the distance from the sensor increases (Hall, 1972; Breiner, 1973). The intensity degrades as a factor of the cube of the distance (Garrison, 1989). Thus, an iron object with a weight of 100 pounds would generate an anomaly undetectable midway between lines spaced on either 30 or 50 m centers. A 2,000 pound iron object would produce a signature of approximately 18 gammas if located midway between lines spaced on 30 m centers and approximately 8 gammas if located midway between lines spaced on 50 m centers. In addition both objects would produce monopolar signatures that would contribute little to either detailed analysis or determining the accurate position of material generating the signature.

While it is accepted in general that 50 m line spacing is insufficient for reliable cultural resource surveys, reducing the line spacing to 30 m does not necessarily resolve the matter (Saltus, 1986; Murphy and Saltus, 1998). Even at 30 m, identifying the remains of small vessels could be a factor of the chance position of a single survey line in relationship to the wreck. An examination of the signatures associated with several significant sites illustrates the problem. The remains of the Confederate submarine CSS *Hunley* produced a magnetic signature of approximately 450 gammas covering an area of 1,200 m^2. If the remains of the submarine were located midway between two 30 m lines that signature could be undetectable (Fig.13). Magnetic contours generated by a survey of the eighteenth century shipwreck, tentatively identified as the remains of the pirate Blackbeard's *Queen Anne's Revenge,* provide another relevant example (Fig. 14). Like the *Hunley*, the Blackbeard wreck remains might not be detected by a survey run on 30 m line spacing. The remains of a small, but historically important, vessel found in the Cooper River near Charleston, South Carolina proved to have no detectable magnetic signature with a survey line right over the wreck and a sensor height 6 m above the bottom. As much of the surviving wreck structure was exposed, the vessel remains were identifiable in sonar records (Fig. 15).

Arnold (1980) used contour plotting of data to illustrate the complex nature of signatures that are refined by combining lines of magnetic data; he was able to reveal a more complex magnetic image that was much more representative of the true anomaly and its location. Using data collected on 18 m (60 ft) line spacing, Bell and Nowak (1993) contoured the data using every line and every other line. The results effectively illustrated that the more intense line spacing generates a more complex signature for analysis and provides a more accurate position

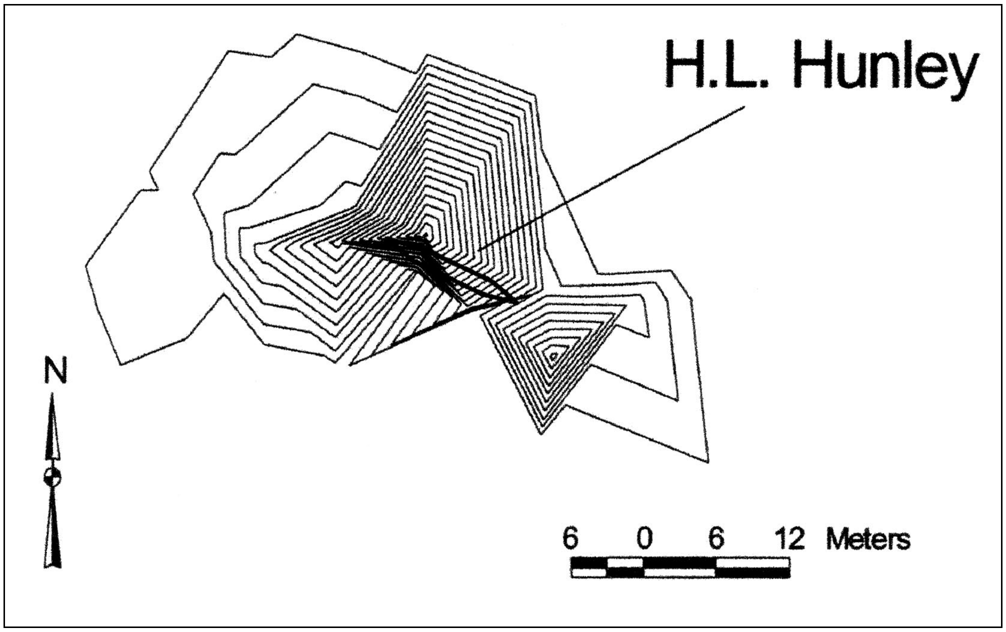

FIGURE 13. Contoured magnetic signature of the Confederate submarine CSS *Hunley* (Image courtesy of Reson and the Naval Historical Center).

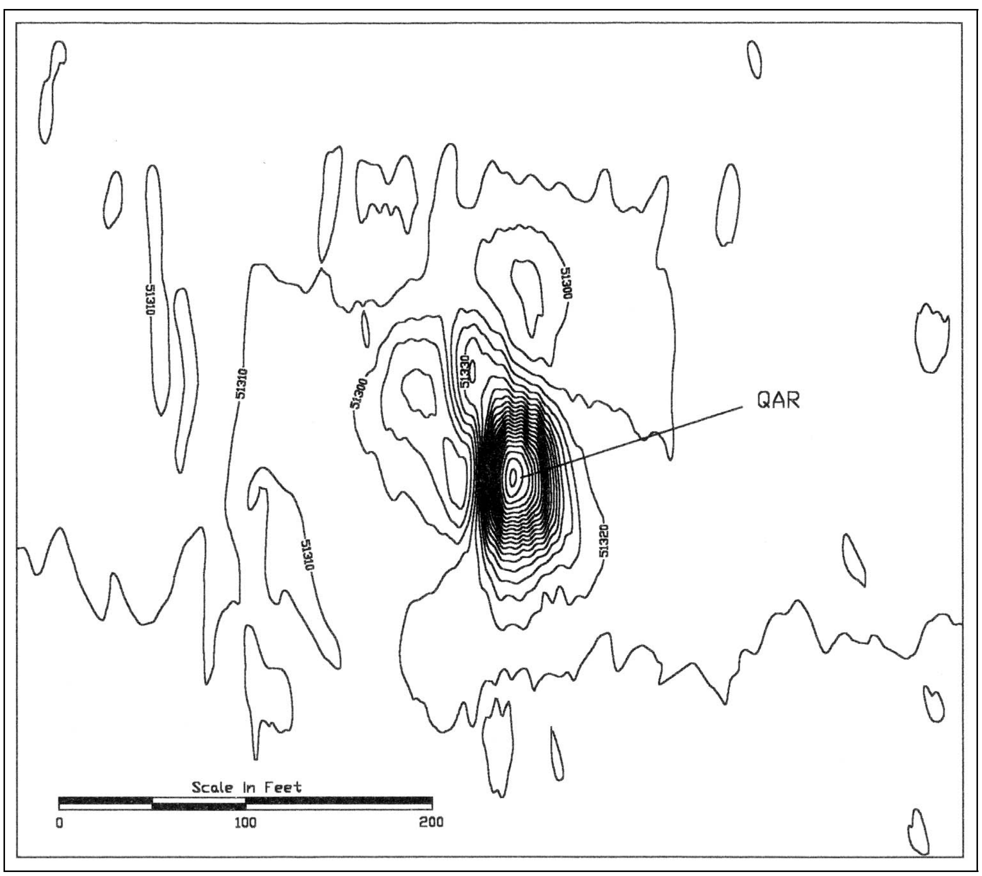

FIGURE 14. Contoured magnetic signature of the Eighteenth century shipwreck identified as the *Queen Anne's Revenge* (Image courtesy of Tidewater Atlantic Research, Inc.).

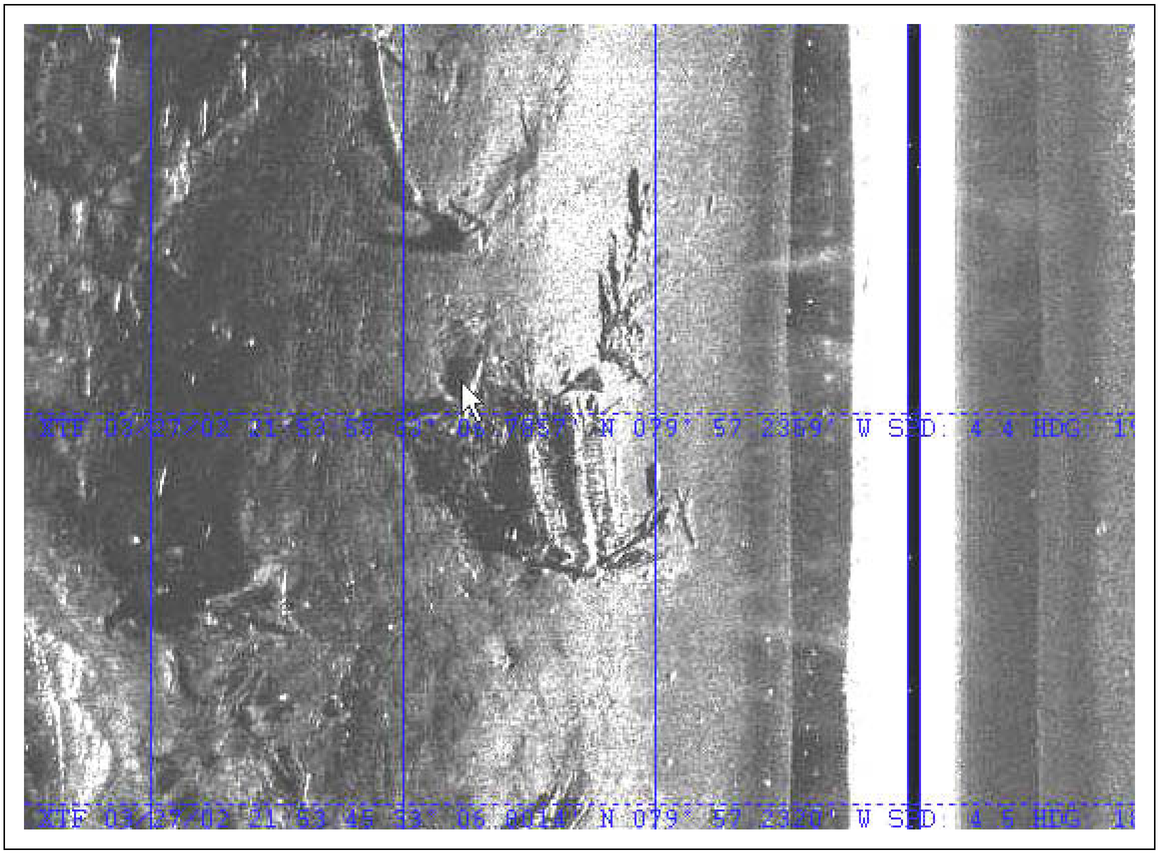

FIGURE 15. High-resolution Klein 500 kHz side scan sonar image of the remains of the Mepkin Abby vessel sunk in the Cooper River near Charleston, South Carolina (Image courtesy of Ralph Wilbanks, Diversified Wilbanks, Inc.).

for material generating the signatures. By using data from alternating 55 m (180 ft) lines, they demonstrated that both the configuration of the anomaly signatures and the apparent location of material generating the signatures were shifted. Bell and Nowak (1993) noted that in contouring data from the 55 m lines, anomalies tended to be centered along the track lines due to insufficient data to develop the signature or accurate positioning. Contouring the magnetic data from a survey of the Union ironclad USS *Patapsco*, sunk in Charleston Harbor in 1864, illustrates the point discussed by Bell and Nowak (1993). Contouring the data from every line run on 23 m (75 ft) spacing produces a complex multi-component signature with good georeferencing (Fig. 16A). Contouring the data from every other line not only reduces the level of signature detail, it shifts the geographical position of the anomaly (Fig. 16 B).

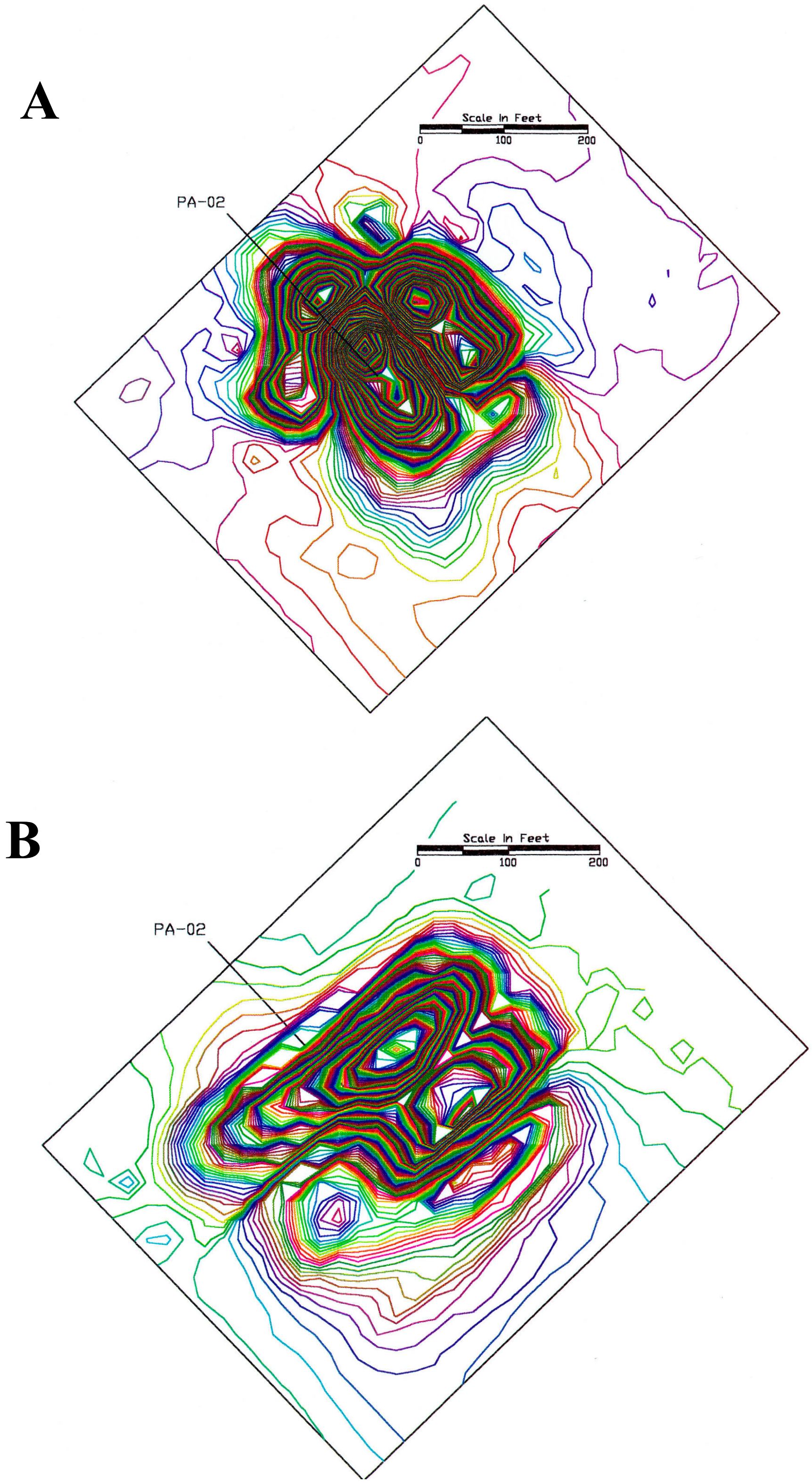

FIGURE 16. Magnetic signature of the Civil War ironclad USS *Patapsco* sunk in Charleston Harbor, South Carolina contoured from data recorded on 75-ft line spacing (A) and 150 ft line spacing (B) (Image courtesy of Tidewater Atlantic Research, Inc.).

Reliable analysis of magnetic signatures depends upon sufficient data, meaning closely spaced survey lines and precision positioning. Contouring of the data is essential for analysis of the anomaly and for determining the position of cultural material generating the magnetic signature. Gearhart (1998) recognized the necessity for contouring magnetic data in analyzing anomalies in his assessment of the signatures of the *King Philip* and *Reporter* on Ocean Beach, San Francisco.

In addition to recommending that line spacing in sand borrow areas be reduced to 30 m, collecting additional data on more closely spaced lines is also recommended for more comprehensive anomaly analysis. While additional data and contouring will not resolve all of the complications associated with magnetic signature analysis, 30 m line spacing can help solve some of the problems associated with a formula for potential significance based entirely on intensity and duration.

7.3 Agency and Institution Survey Line Spacing Requirements

In canvassing agencies, institutions, contractors and individuals associated with submerged cultural resource research, protection and management it is apparent that a 30 m (100 ft) line spacing is becoming the standard for remote sensing surveys. Several states with formalized requirements for remote sensing surveys have adopted the 30 m line spacing for inshore waters.

Florida has adopted a 30 m line spacing inside the 100-ft contour but permits surveys to be carried out on a 50 m line spacing outside the 100-foot contour (Florida Division of Historical Resources, 2003). Guidelines for remote sensing surveys in Mississippi prepared by the Mississippi Department of Archives and History and the SHPO have established 30 m as the maximum line spacing for submerged cultural resource remote sensing surveys. In addition where anomalies have an intensity of more than 20/25 gammas and influence an area greater than 15 m, additional data are required (Mississippi Division of Archives and History, 2003). The Texas Historical Commission (2003) requires a 30 m line spacing for submerged cultural resource surveys. The South Carolina Institute of Archaeology and Anthropology has not formally adopted standards for survey line spacing but suggests project specific data collection guidelines such as 15 m line spacing in high sensitivity areas where small colonial vessels might be found (Spirek, 2003). In North Carolina waters the Underwater Archaeology Unit of the Department of Cultural Resources recommends line spacing on a project-specific basis but generally suggests 18 m (60 feet) survey line spacing (Lawrence, 2003). The Maryland Historical Trust, like the majority of state agencies, recommends survey line spacing on a project-specific basis (Bilicki, 2003).

USACE Districts vary in their requirements for submerged cultural resources. The Mobile District employs a maximum line spacing of 50 m and, where targets are identified, additional data are required on closer line spacing (Gibbens, 2003). In areas under the jurisdiction of the Wilmington District, 20-30 m survey line spacing is normally required for submerged cultural resource surveys (Kimmel, 2003). The Jacksonville District recommends 23 m (75 ft) line spacing offshore and closer intervals inshore. Targets require two additional lines of data to facilitate locations and analysis (Birchett, 2003).

The NPS has adopted 30 m line spacing for their surveys, unless the area is one of high sensitivity (Bradford et al., 2003). For submerged cultural resource surveys the National Oceanic and Atmospheric Administration generally follows the data collection policies of their Office of Ocean Survey or the recommendations of the NPS (Broadwater, 2003).

The Lighthouse Archaeological Maritime Program associated with the St. Augustine Lighthouse and Museum, Inc. has adopted 15 m line spacing for their remote-sensing surveys as their research indicates small and early vessels may not be reliably detected at 30 m (Morris, 2003). The Institute for International Maritime Research, Inc. has adopted 15 m line spacing where survey activity is associated with efforts to identify early shipwreck sites.

8.0 BUFFER ZONES

Avoidance is perhaps the most common option adopted when potentially significant anomalies are located in a project area. That option is usually associated with the establishment of a restricted zone surrounding the anomaly to protect the site from damage or destruction by proposed project activities. Zones of avoidance, or buffer zones, are generally established with some consideration for the areal extent of the anomaly, environmental conditions, and the nature of proposed project activities. In virtually all cases, criteria for zones of avoidance reflect site-specific priorities and are based on individual opinion or preference.

MMS has no established standard for zones of avoidance. A survey of other Federal and State agencies indicates that there are literally no formally established standards for zones of avoidance associated with submerged cultural resources. With the exception of Texas, where the Texas Historical Commission requires a 50 m “avoidance margin” for avoidance in inshore waters, there are no established standards for buffer zones among either state or federal agencies. In contacting the National Oceanic and Atmospheric Administration, NPS, the Navy Historical Center, and USACE District offices, it was apparent that no standards have been adopted and decisions on zones of avoidance are made on a case-by-case basis.

8.1 Buffer Zone Criteria

One of the key factors in determining the size of areas of avoidance is the areal extent of the magnetic or acoustic anomaly. The larger the anomaly is, the larger the perimeter of the zone of avoidance. An exception to that generalization is where anomalies lie in or adjacent to navigation channels. In those areas zones of avoidance may be more restricted due to limits on the channel alignment. Another factor given consideration is the depth of dredging. The ultimate angle of repose of sediment in the vicinity of an anomaly or submerged cultural resource is a major factor in the size of the zone of avoidance. Water depth, currents, surface energy and sediment type receive some consideration, but virtually no information exists on their impact on the stability of sediments in zones of avoidance. In most cases, zones of avoidance are circles centered on the anomaly or submerged cultural resource.

Size appears to range from 60 m (200 feet) in diameter for small unidentified anomalies, to almost 300 m (1,000 feet) for shipwreck scatters (Birchett, 2003). One inshore example is the "Dixie Crystal" wreck site in St Augustine, Florida where a 60 m buffer was negotiated with the SHPO (Birchett, 2003). In the case of the CSS *Georgia*, the area restricted from dredging (Fig. 17) is a polygon determined both by channel parameters and the extent of wreckage (U.S. Army Corps of Engineers, 2002). For the remains of the Civil War steam tug USS *Narcissus*, which lays in a proposed borrow area, the Florida Division of Historic Resources (2003) placed a 500 m (500 yards) buffer around the site to ensure that remains of the tug would not be adversely impacted by dredging (Smith, 2003). The Historic Preservation Field Services Bureau of the New York State Office of Parks, Recreation and Historic Preservation has recommended that anomalies identified as potentially significant and National Register eligible submerged cultural resources are to be protected by a buffer or zone of avoidance 60 m beyond the limits of the resource (Kuhn, 2003).

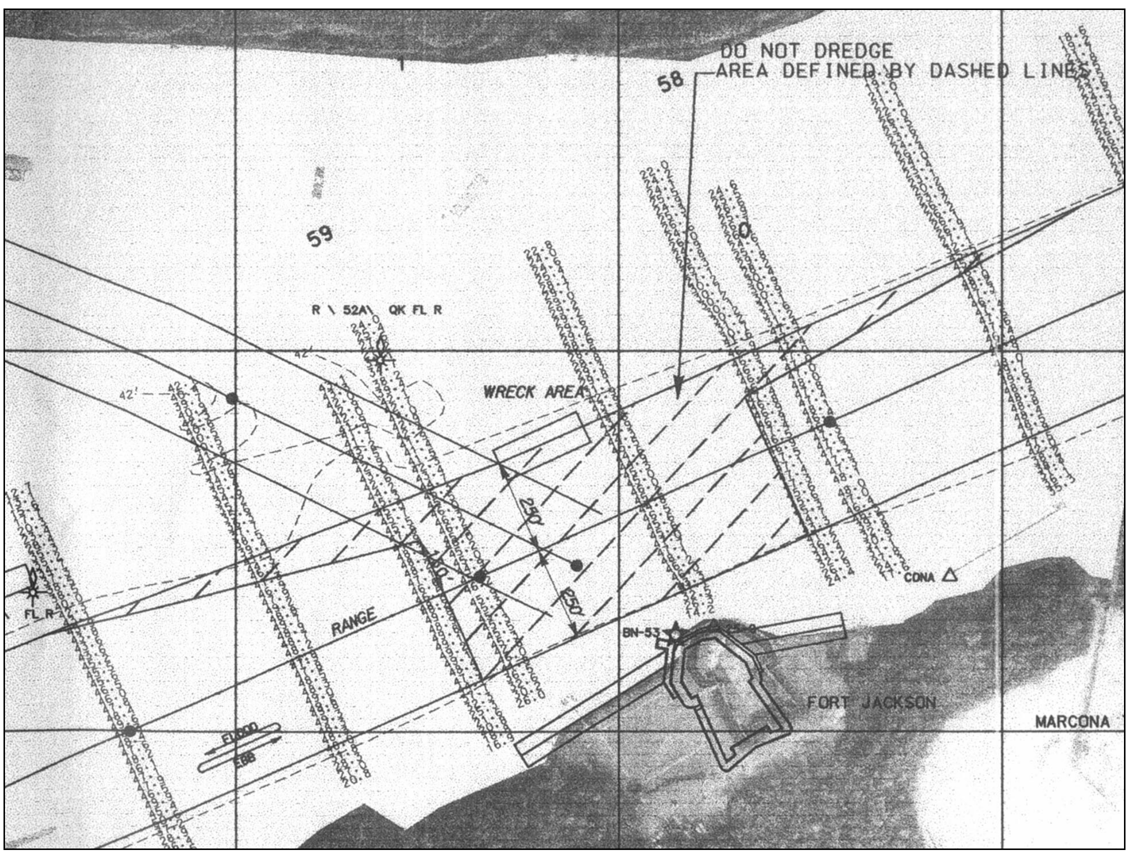

FIGURE 17. Buffer zone established by the Savannah District USACE to protect the remains of the Confederate ironclad CSS *Georgia*. (Illustration courtesy of the USACE Savannah District).

8.2 Buffer Zone Design Considerations

A number of factors are, or should be, considered in defining buffer zones. Two of the most critical factors are the precise geographical location and the actual areal extent of the anomaly or the submerged cultural resource. Defining both the location and extent of material at a site is essential to establishing an effective buffer. Where anomalies are recommended for avoidance additional survey lines should be required. Neither the precise location nor the extent of material preserved at a site can be determined from a single line of data. Where material is not exposed on the bottom surface and magnetic data are used to determine areal extent, additional survey lines are an absolute necessity. In most cases additional survey lines are not run to provide those data.

The size of an area of avoidance should also be a factor of the positioning system and dynamic control of the dredge. If the dredge is equipped with state-of-the-art, sub-meter global positioning and running sophisticated dredging software, zones of avoidance can be provided on a navigation file. The software can also be set up to continuously record the position of the dredge to facilitate monitoring. Where positioning and software are not state-of-the-art, larger zones of avoidance may be prudent and monitoring more difficult.

The nature of bottom sediments in the vicinity of an anomaly or submerged cultural resource is also an important factor in defining a zone of avoidance. Where sediments are unconsolidated, such as dynamic sand ridges that contain beach nourishment quality sand, the ultimate angle of repose may be high. That would necessitate a larger zone of avoidance than areas where sediments are more consolidated and composed of more stable mud, clay and mixtures. While sediment profiling is not necessarily a priority for submerged cultural resource remote sensing surveys, subbottom profiling and coring are included in geophysical surveys to locate suitable sand deposits. An examination of those data should provide sufficient information to evaluate sediment stability and post dredging migration. Data from decades of determining channel prism slopes should also be useful in evaluating these factors.

Currents and surface motion energy are equally important factors in determining both the size and shape of zones of avoidance. Currents play a major role in the formation, reformation and migration of sand ridges. The impact of dredging away portions of those dynamic deposits has not been established. Changing the physical properties of a sand ridge or deposit could seriously impact its relationship with the water column environment compromising overall stability and resulting in changes that undermine even the broadest zones of avoidance (Research Planning, Inc. et al., 2001). Assessing the impact of currents and surface energy transfer would require extensive testing and monitoring.

The traditional shape of zones of avoidance is a circle. However in areas where currents exist, wave energy is high and bottom sediments are unconsolidated that configuration might not be the most appropriate. Anticipated erosion or migration might require elongated shapes to afford the desired protection until the bottom stabilizes. Where sediments around zones of avoidance are removed, the resulting pedestal is likely to create a hydrostatic dam changing both the water column and surface motion dynamics. That could result in accelerated erosion of the sediments left undisturbed to protect a site.

Although computer modeling has not generally been employed in efforts to determine the fate of a dredged depression in the seabed, modeling has been used to assess the fate of dredge disposal mounds on the seabed. The USACE has developed the LTFATE (Version 2) model that simulates the long-term fate of dredge disposal mounds in response to sediment transport generated by waves and currents (Gailani, 2002). This model has been successfully tested in simulating the evolution of dredge disposal mounds on a flat seabed. Most borrow deposits presently identified by MMS consist of ridge and shoal features (Nairn et al., 2004) and Hayes and Nairn (2004) have noted the importance in understanding the nearshore wave transformation to accurately predict the evolution of these features in response to dredging. The LTFATE model assumes that the wave and current conditions are spatially constant, which is not the case at most borrow deposits currently identified by MMS. Nevertheless, it is possible that the LTFATE model (or a similar approach) could be combined with appropriate models for wave transformation and hydrodynamics (giving spatially varying waves and currents) to assist in an evaluation of the future evolution of a borrow deposit to more specifically quantify buffer zone requirements around archeological resources.

8.3 Proposed Formula for Establishing Buffer Zones to Protect a Site from Exposure

Certain factors must be taken into account to avoid loss or damage to the archeological resource by exposure from the seabed. The minimum distance from the resource to the Dredge Limit Line may be determined by considering the following parameters:

- A buffer zone to compensate for the level of confidence in the resource location process or degree of scatter of the resource;
- A minimum slope estimated from local parameters or a minimum of 1:100 (v:h);
- An uncertainty buffer related to the dredging equipment positioning (including potential human error or equipment malfunction); and
- The elevation of the top of the resource and the final grade of the borrow area after all dredging is completed.

Figure 18 is a diagram showing the relationship of these parameters to the minimum Dredge Limit Line.

There is an argument that the three factors (resource location uncertainty, dredge position uncertainty and slope allowance) should be fully additive, however, this approach would result in a very large buffer that may be too conservative. On the other hand, it is very unlikely that, if an error occurred in dredge position, it would result in the entire dredge limit being shifted towards the archeological resource (i.e., over the full length of the deposit).

Therefore, as a more balanced approach, two relationships were developed by pairing two of the three buffer allowances. To apply these formulas, the user should choose the greatest buffer width resulting from the two equations.

$$L1 = Ub + Bz \qquad (1)$$

$$L2 = Ub + Dd/S \qquad (2)$$

Where:

L = Distance to dredge limit
Ub = Uncertainty buffer for the resource location (possibly some percentage of the width of the resource footprint)
Bz = Dredge Buffer zone
Dd = Cumulative depth of dredging from original sea bed elevation
S = final slope

The equations above make the conservative assumption that the toe of the ultimate slope develops from the position of the edge of the borrow deposit (i.e., there is no sloughing of the slope into the borrow area). For a dredge depth of 3 m below the initial seabed level, a resource uncertainty buffer of 50 m, a dredge buffer zone of 100m and a slope of 1:100, the buffer from the edge of the known resource to the edge of the borrow deposit would be L1= 150 m and L2=350 m thus L2 would be applied.

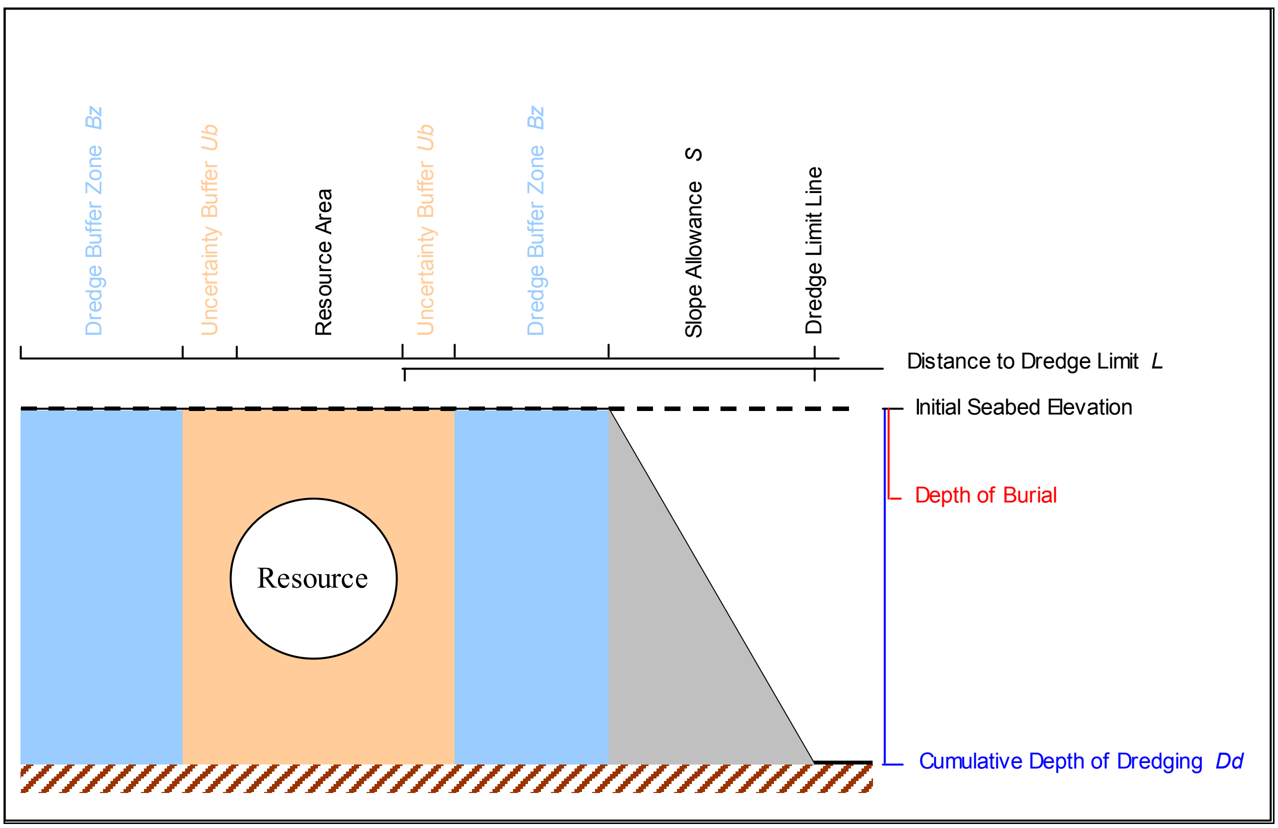

FIGURE 18. Diagram showing the parameters for calculating site-specific buffer zones.

Figure 19 contains a series of plots that were developed using formulas 1 and 2 where the depth of dredging (X axis) is used to determine the distance from the edge of the resource to the dredge limit line (Y axis) with different slope allowances (blue lines) and different dredge position uncertainty buffers (red lines). It also accounts for an uncertainty buffer for the resource location (*Ub*) of 50 m. The user should choose the greatest distance (*L*) resulting from the two methods.

The elevation of the resource, the minimum cover, and the buffer zone distance to cover the inaccuracies in the dredging and the inaccuracies in the location of the resource and degree of scatter must be determined for each site. The slope may be taken as 1:100 (v:h) or calculated by slope stability analysis. According to BMAPA and English Heritage (Wessex Archaeology, 2003), a buffer zone must be established depending on site-specific characteristics (i.e., available data on geology, hydrology and sediment transport) in order to guarantee stability of the resource.

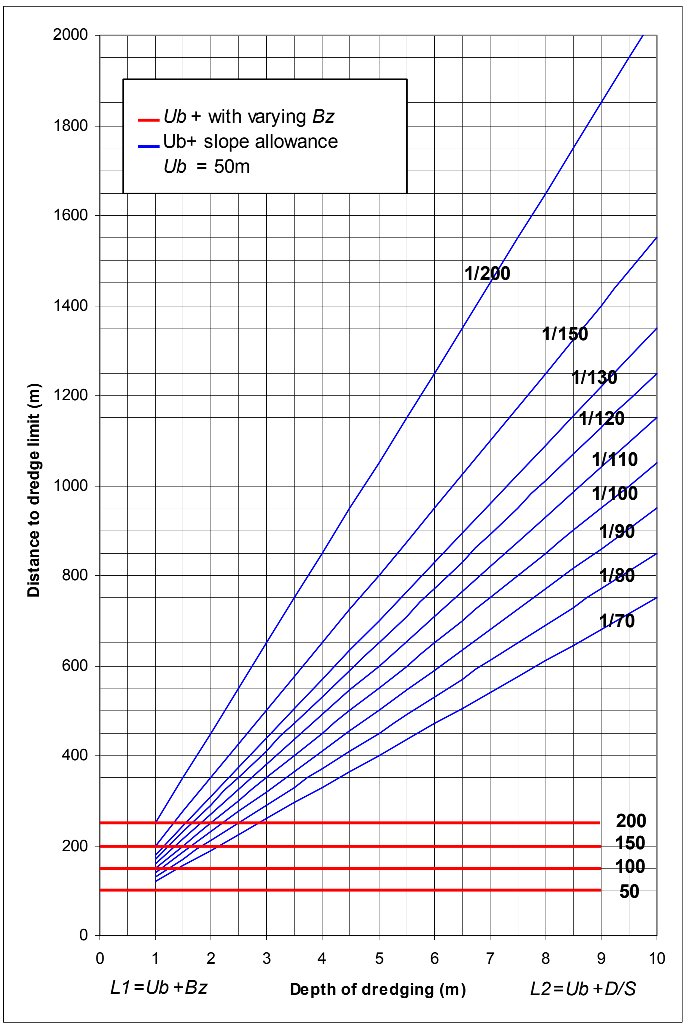

FIGURE 19. Distance from edge of resource to dredge limit line with different slope conditions.

8.4 Preventing Formation of Pedestals

When a buffer or exclusionary zone is extended completely around an archeological resource, there is a potential to develop a “pedestal” of sand if the dredged area also surrounds the resource. A “pedestal” is defined as the situation where the top of the required minimum depth of cover over a resource (or the archeological resource) protrudes above the adjacent bed level after dredging. Any bed form extending above the bed will be subject to change either through migration or erosion. Over time, the sand cover extending over the archaeological resource will erode and the resource will be exposed thereby creating a situation where the foundation of the resource may become unstable. It is anticipated that most of the OCS borrow sites will be in water depths greater than 10 m. If the protrusion of the pedestal is relatively small in these depths, the migration/erosion process will be very slow. However, with archeological resources, long-term integrity is a requirement. This long-term requirement necessitates a site-specific study including hydrodynamic and sediment transport reviews to assure stability.

For the pedestal condition to be avoided, the borrow area should not wrap around the resource. This stipulation could be modified on a site-specific basis, provided it is supported by appropriate hydrodynamic and sediment transport investigation. For example, if there is a clear direction of sand transport at the borrow site, it may be possible to have an arc greater than 180 degrees (but not a full 360 degrees) providing the direction of sand transport and migration of the dredged slope is directed away from the resource (Fig. 20).

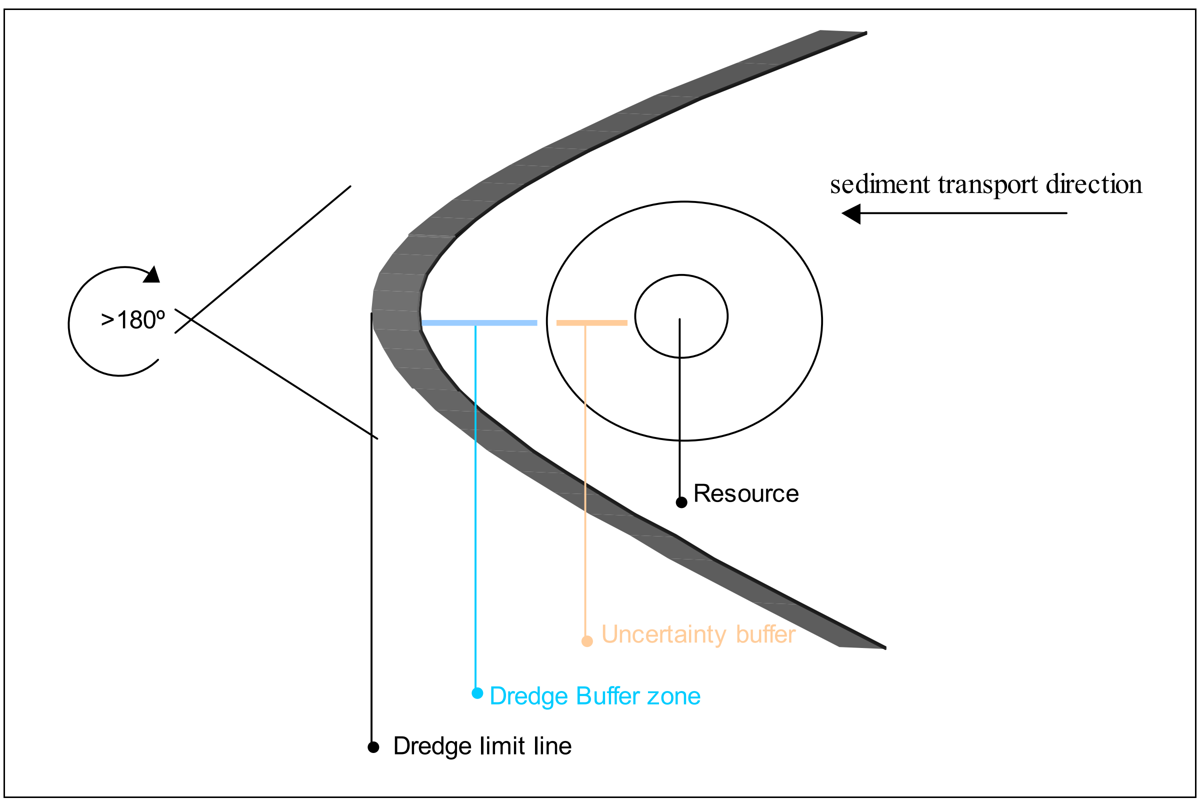

FIGURE 20. Guideline for dredging around a resource to prevent development of pedestals.

8.5 Buffer Zone Monitoring

Where buffer zones have been established to protect an anomaly or submerged cultural resource, a program of monitoring appears to be the only practical means of determining how effective the buffer is working. To make monitoring effective, a baseline definition of the site must be developed. Data to support baseline development should be collected during the initial submerged cultural resource survey if it is apparent that the anomaly or submerged cultural resource will be recommended for avoidance. The baseline survey should include a detailed magnetic contour map, high-resolution sonar imagery mosaicked to illustrate the area of the buffer zone, and a high-resolution multibeam survey to support production of a geographically referenced three-dimensional image of the bottom surface in the buffer zone. GPS RTK positioning and state-of-the-art navigation software should be used to control the survey and data collection to ensure repeatable data.

Where material is exposed on the bottom surface, baseline data should be enhanced by diver documentation. Identification and documentation of exposed material would contribute to a more complex definition of the protected resource and a better understanding of what is at risk. Where anomalies have disappeared and wreck remains have been completely removed with no prior documentation, there is little that can be said about what has been lost.

Monitoring should start with the advent of dredging. Given the record of dredge companies that have damaged or destroyed submerged cultural resources, monitoring is going to be effective only if an independent observer is on-board to observe operations. Where dredges are not equipped with RTK positioning and state-of-the-art navigation software, a portable kit could be developed for the monitor to install on the dredge. This would permit the position of the dredge to be observed in real time in association with the buffer or buffers in the borrow area. Expecting dredge operators to halt operations and report damage to submerged cultural resources in naïve. Monitoring must be carried out independently to be effective and reliable.

Following dredging, a second survey should be carried out to document any immediate changes in the buffer zone and characterize the effects of dredging in the area surrounding the buffer. Comparison of those data with that collected prior to dredging would provide insight into the most immediate impacts on the anomalies and submerged cultural resources that require protection. To assess long-term changes in the buffer zone environment, scheduled and weather related resurveying of the area should be undertaken.

In a MMS study related to possible offshore dredging impacts (Research Planning, Inc. et al., 2001), the following six elements for post dredging monitoring were identified:

- Benthic Communities and their Trophic Relationship to Fish;
- Marine Mammals and Wild life;
- Sediment Sampling and Analysis;
- Wave Monitoring and Modeling;
- Bathymetric and Substrate Surveys; and
- Shoreline Monitoring and Modeling.

For each one of the above elements, a monitoring protocol was developed with focus to the impacts within the borrow areas as well as the near and far field (shoreline changes).
The last three of the above protocols in part address the stability of the dredge site itself. It is recommended that these protocols be modified to address the monitoring requirements associated with dredging near archeological resources.

9.0 RECOMMENDATIONS TO AVOID ADVERSE IMPACTS TO ARCHAEOLOGICAL RESOURCES DURING DREDGING

Recommendations to avoid adverse impacts to archaeological resources during dredging in the OCS are organized into the seven categories listed below. Table 6 is a summary of the suggested changes to the MMS requirements for archaeological survey methods, which fall under several categories.

1. GIS-based data management;
2. Defining the potential archaeological resource base;
3. State-of-the-art means of locating and identifying those resources;
4. Establishing buffer zones for their protection;
5. Dredging operations;
6. Monitoring activities that impact submerged archaeological resources; and
7. Archaeological report and data delivery requirements.

9.1 Geographic Information System-Based Management

The key to effective management is knowledge and communication. Managing all the archaeological resources that lie in the borrow areas identified by MMS will require a multi-faceted data intensive program. One of the most functional and effective methods of storing, retrieving, and managing data is a GIS. One of the highest recommendations for management of submerged cultural resources in sand borrow areas under the jurisdiction of MMS is to establish and maintain a GIS for management, research, and monitoring.

All geographic data files should be delivered in one or more georeferenced digital formats. The recommended delivery format is SDTS, Arc Export (E00) or ArcView shapefile. All geospatial data should be submitted in the following datum and coordinate systems: North American Datum 1927 and 1983 (both NAD27 and NAD83 are required), and Universal Transverse Mercator grid. All digital geospatial data products are to be accompanied by complete metadata documentation in the Federal Geospatial Data Committee Content Standard for Digital Geospatial Metadata format.

9.2 Refining, Refocusing, and Testing Baseline Studies

MMS management of submerged cultural resources is essentially based on a series of baseline studies carried out over two decades ago. Those baseline studies have been refined and,

TABLE 6. Summary of the suggested changes to the MMS requirements for archaeological resource surveys.

Recommended Changes in MMS Survey Guidelines		
Guideline		
II. Archaeological Resource Survey Navigation		
	Current Requirement	**Recommended Requirement**
Positioning Accuracy	5 m	1 meter
Fix Logging	12.5 m	1 second
Shot Points/Event Marks	152 m	30 m
III. Archaeological Resource Survey Patterns		
	Current Requirement	**Recommended Requirement**
Line Spacing		
(High Probability Areas)	50 m	30 m
Lines for Anomaly Definition	0	10 m on each side of initial contact line to background
A. Magnetometer	**Current Requirement**	**Recommended Requirement**
Type	Proton or Cesium	Digital Proton, Cesium, Overhauser
Data Recording	Strip chart & digital	Digital integrated with DGPS through
B. Dual Channel Sidescan Sonar	**Current Requirement**	**Recommended Requirement**
Frequency	300 to 500 kHz	300 to 900 kHz
Line Spacing		
(High Probability Areas)	50 m	30 m
Lines for Anomaly Definition	0	10 m on each side of initial contact
Data Recording	Graphic & Digital	Digital integrated with DGPS through computer
Range/Coverage	100%	150%
C. Subbottom Profiler	**Current Requirement**	**Recommended Requirement**
Frequency	1.5 to 4.5 kHz	1.5 to 220 kHz Chirp
Data Recording	Graphic & Digital	Digital integrated with DGPS through
Motion Correction	None	Heave, pitch and roll compensated
D. Depth Sounder	**Current Requirement**	**Recommended Requirement**
Type	Single beam	Multibeam
Data Recording	Graphic & Digital	Digital integrated with DGPS through
Motion Correction	Heave compensated	Heave, pitch and roll compensated

to a degree, tested in the Gulf of Mexico. However in the Atlantic, little subsequent attention has been focused on those baseline issues.

As the nature, scope and distribution of prehistoric and shipwreck resources are key elements in developing a responsible and effective management program, a comprehensive reexamination of those issues is highly recommended. Refined prehistoric and shipwreck models could be tested using data that will be generated by investigations designed to locate and identify submerged cultural resources in the OCS sand borrow areas.

Because the application of terrestrial models for prehistoric habitation to the continental shelf environment has not been demonstrated, consideration should be given to using remote sensing data, computer modeling of relic landforms, and computer control of dredge navigation and excavation systems to test that hypothesis. Detailed acoustic remote sensing data could be generated and employed to develop three-dimensional computer models of a proposed borrow area and the relic landforms that survive in the stratigraphic record. Using terrestrial models for prehistoric site location, areas of potential could be identified. If those areas contained suitable beach nourishment material a program of monitoring could be developed to identify cultural material in the dredge spoil in conjunction with excavation in areas of interest. In the event that cultural material was identified, dredging could be shifted to another location and the geographical source of cultural material examined by archaeological divers.

9.3 Remote Sensing Equipment and Survey Methods for Location and Identification

Although the basic remote-sensing survey equipment groups remain essentially the same, technological advances have greatly improved the accuracy, efficiency, and reliability of remote sensing investigations.

9.3.1 Digital Data Display, Recording, and Storage

Virtually all remote-sensing survey instruments now record data digitally and onboard display is via computer. Geographical positioning for magnetic and acoustic data is also recorded almost exclusively by computer, which eliminates the necessity for maintaining a strip chart recorder and annotating the record with positioning data. That requirement could be dropped from the survey requirements without compromising data collection or storage.

9.3.2 Digital Magnetometer Systems

Magnetometer testing carried out by Panamerican Consultants (2003) strongly suggests that new design proton, cesium, and Overhauser magnetometers produce better data than older proton precession instruments. Based on their data it would seem that state-of-the-art surveys should include one of the new digital systems. If for no other reason, their low noise capability makes identification of subtle targets more likely.

Although the current requirements do not require contouring the magnetic data for target assessment or reporting, this procedure is considered an essential step in data analysis. Contouring magnetic data should be considered for inclusion in future MMS survey requirements.

Where magnetic targets are considered for potential significance, additional magnetic data should be collected to permit detailed contouring, more comprehensive analysis and better positioning for material generating the signature. Single lines of data at 50 m spacing do not contain sufficient information for either target location or signature characteristic assessment. Even at 30 m survey line spacing, targets identified for additional investigation or avoidance should be refined.

A sufficient number of lines on either side of the original survey line should be run to determine the areal extent and location of material generating the signature. Targets identified for additional investigation or avoidance should be individually contoured for analysis and reporting. This method of investigation, analysis, and reporting represents the state-of-the-art.

9.3.3 Digital Sonar Systems

Sidescan sonar technology has also improved significantly in the last two decades. New digital machines are generally capable of higher resolution than older analog equipment and should be required for submerged cultural resource surveys. Most are equipped with sophisticated software that permits post survey data manipulation, mosaicking, and GIS integration. Target analysis and location is much improved by the capacity to review records and determine anomaly characteristics, location, and dimensions.

Like magnetometers, the closer the sonar transducer is to the target, the lower the necessary range and, in general, the more detailed the image. Current MMS range scale settings were established to produce 100% coverage of the survey area. Because resolution is not as high at the periphery of the range as it is closer to the sensor, range scales should be set to provide at least 50% overlapping coverage between survey lines. That overlap in coverage provides additional assurance that objects midway between survey lines will be imaged and identified. Regardless of the survey line spacing and sonar range setting, where sonar images are associated with an anomaly identified for additional investigation or avoidance, target specific sonar data should be collected to refine the image. The most diagnostic images require detailed inspection.

Another recommendation is to consider requiring dual frequency instruments. Sonars are now designed to record simultaneous dual frequency data. That capability frequently proves to be beneficial. Layers of light suspended sediment above the bottom surface and water column "noise" can inhibit bottom surface resolution on a 500 to 1200 kHz frequency. Those factors do not have as dramatic a degrading effect on the resolution of a 100 to 200 kHz frequency system. A dual frequency sonar requirement should be considered.

9.3.4 High Resolution Chirp Subbottom Profilers

New high-resolution chirp subbottom profilers are capable of resolving stratigraphic features with sub-meter accuracy. For delineating cultural resources in areas to be dredged, that level of accuracy is important and should be considered as a requirement for assessing the depth, distribution, and characteristics of buried material to be isolated by buffer zones. Like the intensive target specific sonar and magnetometer surveys, the subbottom profiler should be run on a much-reduced line spacing for refining signature characteristics. In addition, subbottom surveys should be run in conjunction with heave, pitch, and roll compensation equipment to improve record quality.

9.3.5 High Resolution Multibeam Echo Sounders

Serious consideration should be given to including a multibeam echosounder system in the equipment requirements for submerged cultural resource surveys in borrow areas. The multibeam is capable of collecting the highly accurate, three-dimensional data necessary for mapping the bottom surface. That level of definition is essential in characterizing and assessing the impacts of dredging. High-resolution multibeam imaging of the bottom surface will also provide the detailed baseline data necessary for monitoring post-dredging environmental changes in buffer zones. Multibeam echo sounders should be run in conjunction with heave, pitch and roll compensation equipment to improve accuracy and record quality. Use of a multibeam system would make the depth sounder an unnecessary requirement.

9.3.6 Differential Global Positioning

To georeference and compare magnetic and acoustic data, highly accurate positioning is necessary. Sub-meter accuracy is available and highly reliable with GPS systems that are equipped for real time kinematic corrections. That level of accuracy is critical for sophisticated mosaicking of acoustic data. It is also necessary if sophisticated comparison of imagery is to be used to monitor environmental change over time. High-accuracy positioning is also essential in georeferencing target locations, determining areal extent, and establishing buffer zones. Sub-meter RTK positioning should be considered as a requirement for all submerged cultural resource investigations in the offshore borrow areas.

9.3.7 Submerged Cultural Resource Survey Line Spacing and Anomaly Definition

It has been widely accepted for decades that closer line spacing produces more and better data. Today most cultural resource surveys are run at a maximum of 30 m (100 ft) line spacing. In areas close to shore or where historical research suggests that shipwreck resources are a high probability, 15 m (50 ft) line spacing may be recommended or required. That spacing is being adopted for most research-oriented surveys where small vessels and targets are as important as larger ones. A maximum line spacing of 30 m (100 ft) is recommended for consideration as the standard for remote sensing surveys in borrow areas. Furthermore, the survey for archeological resources should extend at least 500 m beyond the edge of the borrow deposit.

Regardless of line spacing, detailed investigation of anomalies is recommended strongly. Material generating magnetic targets defined by only one line of data cannot be located reliably. Signature characteristics and areal extent cannot be determined without collateral data. To be diagnostic, sonar images must be sufficiently detailed. That detail is the product of a combination of factors that include frequency, range, transducer elevation, speed, and line-to-target orientation. These requirements are achieved rarely on preliminary coverage survey lines. Where targets are analyzed for potential historical significance, additional coverage is essential.

9.4 Buffer Zones

In assessing the issue of buffer zones, there is little beyond individual opinion to consider. Agencies that have adopted specific buffer requirements have done so without scientific analysis or testing. While circles are the almost universal shape, size varies from 30 m to over 300 m. These two parameters have no basis in tested hypothesis. An equation has been proposed to develop a site-specific buffer. There are three areas of uncertainty that must be addressed in this deterministic approach to defining appropriate types of buffer zones:

1. Accuracy of dredge positioning considering the true navigational accuracy, potential for operator error, and potential for power loss;
2. Uncertainty on locating all of the resource; and
3. Ultimate stable slope.

Buffer zones also need to address the issue that the development of full pedestals must be avoided. It is possible that in some specific instances partial pedestals may be allowed if the sediment transport direction is well defined and uni-directional. However, MMS should consider a program of research designed to develop and test a formula for buffer zone definition. In refining the proposed formula for buffer zones in offshore borrow areas, modeling could be of considerable assistance. Computer modeling may be an effective means of determining the influence of dynamic environmental and human factors on buffer zones designed to protect submerged cultural resources. Bringing the problem to the attention of the USACE might help determine if computer modeling could be of assistance.

A second consideration might be to establish a series of test buffers within an area to be dredged and monitor their stability over time. These could be established in areas where submerged cultural resources are not present. Monitoring those zones would provide insight into their stability and effectiveness.

The buffer zone should be defined using a latitude/longitude coordinate system. When delineating the limits of the buffer zone, several factors must be taken into account. The value of the resource may play a role in the selection of the dimensions of the buffer zone as will the confidence in the surveyed location of the resource. The distribution of the artifacts from the resource may be an important factor on the size and shape of the buffer zone.

Because the nature and scope of prehistoric sites on the continental shelf have yet to be established and the association of prehistoric archaeological sites and relic landforms have yet been confirmed and defined, it is difficult to assess the design of zones of avoidance for those features. If avoidance is determined to be the most appropriate option for preserving relic landforms with a potential association with submerged prehistoric sites, development of a buffer zone should be based on a detailed map of relic landforms. The formula for buffer zone design and extent should reflect the parameters applied to historic shipwrecks.

9.5 Dredging Operations

The greatest risk to archaeological resources during dredging is direct disturbance of the site. Sedimentation related to spilling from hoppers or turbidity on the bottom in most cases will not negatively impact resources, particularly when the buffer width is greater than 100-200 m. Therefore, it is most important that the position of the dredging equipment be tracked with precision relative to buffer zones. The lease to mine sand on the OCS should include the requirement that all mining equipment be equipped with DGPS positioning equipment and dredging software designed to control and document dredging activity in areas with historic or prehistoric site potential. Figure 21 shows an example screen from commercially available

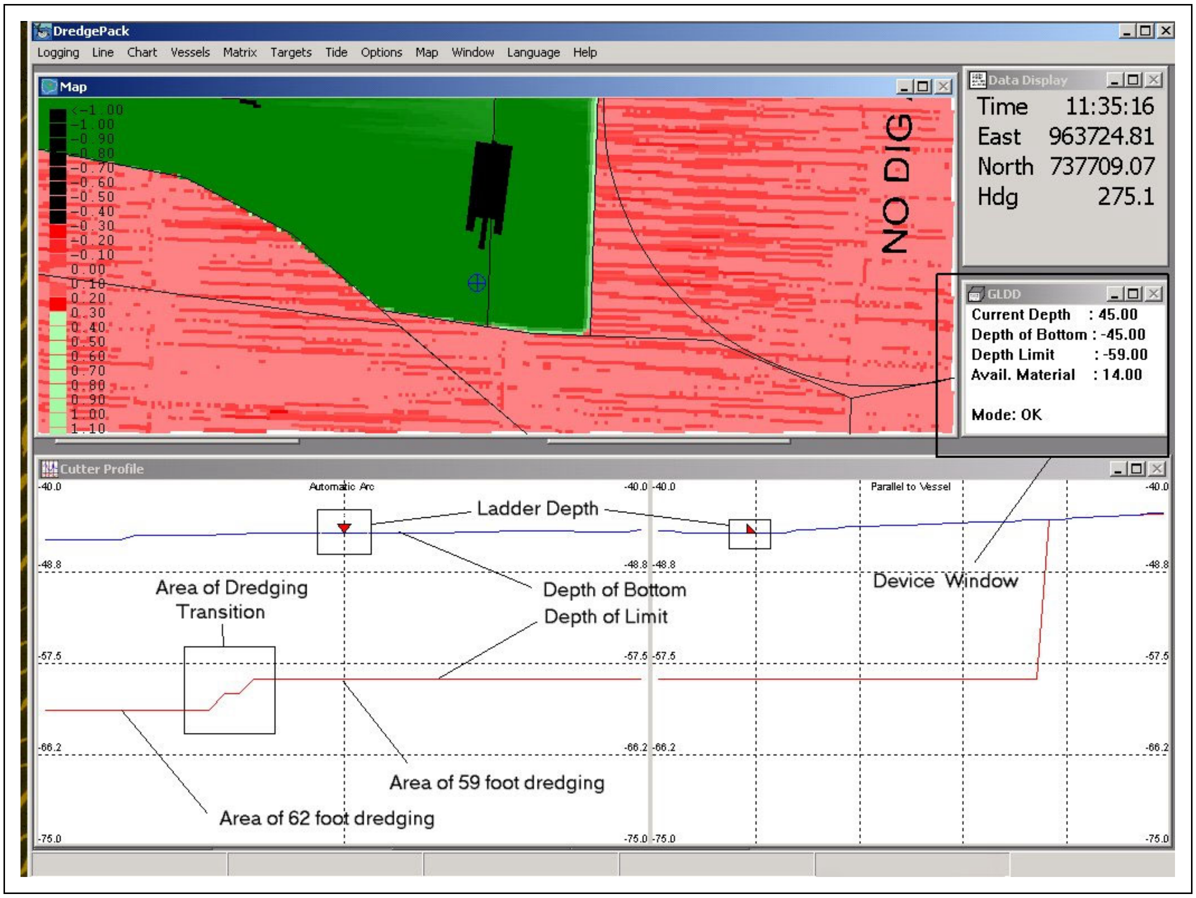

FIGURE 21. A screen from the software DREDGEPACK. The dredge is positioned near a transition point in the dredging project. Several items have been identified in the image. The device window shows the Current Depth, Depth of Bottom, Depth Limit, Depth of Available Material and the Current Mode if there is a violation or not. In the Map window a color filled matrix is displayed showing the current difference values for each cell. The color settings are set from -1 to 10. These values represent the difference between how much material is in the cell against the theoretical limit within that cell. If the operator violates the limit an alarm is sounded and displayed on the Survey screen. As the ladder transitions between depth limits, no operator interaction is required to reconfigure the software. Because the difference and the limit depth have been set, each cell acts independently of the others creating a seamless user interface. (Illustration courtesy of Coastal Oceanographics, Middlefield, Connecticut).

dredging software. The positioning system should be used to locate precisely the dredge and the location of the cutterhead, drag arm, and/or bucket (USACE, Wilmington District, 2001). The Dredge Operator should be required to record continuous, real-time positioning of the dredge, by plot or electronic means, and visually display the position during the entire dredge cycle including dredging, turning, sailing, and offloading. The display should also show the limits of the buffer zones. The instrumentation should be capable of sounding an alarm if the dredge approaches the buffer zone limits (USACE Jacksonville District, 2001). A plan or plot of both the track data and the buffer zone(s) should be submitted to MMS upon project completion.

9.6 Monitoring Dredging Activity

There are two types of monitoring that could be implemented to protect cultural resources: during- and post-dredging. For dredge-positioning equipment and buffer zones to be effective, the dredge crew must be alert to the need for preservation of archaeological and historic resources. The Contractor should be required to prepare a plan to preserve these resources. This stipulation could be a part of the environmental protection plan required in Federal contracts. It may be necessary to employ an independent Archaeological Monitor to be on board whenever the dredge is in operation. This procedure is employed by the Ireland Underwater Archaeological Unit. There is precedence for onboard monitors, as many contracts for the USACE require a person on board to monitor for sea turtles.

Relevant literature and personal contact with submerged cultural resource managers suggests strongly that monitoring of dredging activity is the only way to be sure that submerged cultural resources will not be damaged or destroyed. In most of the documented cases, the incidents resulted from the fact the resources had not been located properly or located at all. Buffer zones will not be effective if the resource is not mapped with precision. Scenarios associated with a number of the sites that have been damaged and destroyed seem to confirm the hypothesis that regulations must be monitored and enforced to be effective. It appears unrealistic to expect the dredge company to monitor it's own activity or to cease work when a submerged cultural resource is encountered to report problems to permitting agencies.

Monitoring should be carried out by a knowledgeable archaeologist or individual with training in both historic vessel and artifact recognition and navigation survey software. With an independent GPS and computer navigation system, it would be a simple matter to program in buffer zones and track dredging operations. The Monitor should have authority to halt or alter the location of dredging operations in the event that significant submerged cultural resources are being damaged or destroyed.

Protocols for an onboard Archaeological Monitor should include:

1. Developing a document that provides a clear definition of the resources, the regulations, and the penalties involved;
2. Defining the role and responsibility of project monitors;
3. Identifying channels of communication to be employed in the event of inadvertent contact with submerged cultural resources;
4. Establishing a definition of the resources to be protected;
5. Providing clear definition of known submerged cultural resources in project areas and any buffer zones established to protect them; and
6. Identifying report requirements associated with documenting dredging activity.

Random monitoring of sediment pumped on beaches has been carried out in the past. At Holly Beach, Louisiana examination of beach nourishment material from paleo-stream channels was carried out in late 2003 with no identification of submerged cultural material to date (CP&E, 2003; Pearson, 2004). By correlating the monitoring with dredging in the vicinity of relic landforms, however, the results could be different. Sediment monitoring was also recommended in conjunction with plans to dredge Ship Shoal off the Louisiana coast. Ship Shoal represents the inundated remains of a deltaic headland/barrier island complex with a high potential association with prehistoric archaeological sites (Pearson, 2004).

Random monitoring of sediment pumped on beaches has been carried out in the past with no identification of submerged cultural material (Coastal Planning & Engineering, Inc., 2003). It is important to test the relic landform hypothesis. If avoidance is the option always exercised, that theory can never be tested without funding archaeological investigations. In addition, where cultural materials are found during dredging, an archaeological reconnaissance of the area should be undertaken to determine if it has been resorted by the environment of if an undisturbed archaeological context survived the inundation process.

It is important to test the relic landform/prehistoric site hypothesis. If avoidance is the option always exercised, that theory can never be tested without specific funding archaeological investigations. In addition, where material is identified by dredging, an archaeological reconnaissance of the borrow site should be undertaken to determine if cultural material has been resorted by the environment of if an undisturbed archaeological context survived the inundation process (Faught, 2003; Pearson, 2004).

An alternative approach for resource protection during dredging is a reward/penalty incentive program. Even with precautions, many archaeological and historic resources will be discovered as a result of dredging. Predetermined procedures should be implemented if evidence of a possible archaeological site has been encountered. The archaeological monitor or a member of the crew may observe material in the hopper or on the beach that deserves further investigation. The dredge operator may note erratic behavior of the draghead. The dredge should mark the site and immediately move to a secondary borrow area. Procedures should be in place to notify the MMS. If the site is determined to be of interest, a dive team could investigate under the direction of an archaeologist. If the site is significant, the contractor should be rewarded. This will give the contractor some incentive to report these encounters.

A possible alternative to on-board personnel has been developed and is currently in limited use. Due to the necessity for maintaining quality control on sand dredged for beach nourishment, engineering firms and dredge companies have adopted computer programs to control dredging activity. Using high-resolution georeferenced maps of the borrow area that include subbottom stratigraphy, dredge activity can be programmed in three dimensions. The dredge is programmed to remove material from selected deposits that have been previously identified as suitable for beach nourishment. At the same time, unsuitable material can be avoided (Andrews, 2004).

To ensure that the dredge operations follow the three-dimensional parameters established by remote sensing and coring, real-time data can be transmitted by modem and radio to computer systems onshore. When dredging occurs in areas outside the design parameters of the project, an alarm sounds and the cells in the computer material matrix are turned to a preselected color. This operation has been demonstrated to be effective on a number of projects (Knisley, 2004). In early 2004, contractors are using a system developed by Coastal Oceanographics to tightly control the excavation of beach quality sand off Boca Raton, Florida (Andrews, 2004). If this level of control can be employed to ensure the excavation of beach-quality sand, it can also be employed to control avoidance of relic landforms and schedule monitoring of spoil when the dredge is operating in the vicinity of subbottom features with potential associations with submerged cultural resources.

Following dredging operations, a systematic program of monitoring should be established to compare post-dredging bottom conditions to base line data collected prior to dredging. The remote-sensing equipment employed for monitoring should reflect state-of-the-art magnetic and acoustic data collection with high accuracy positioning and sophisticated software. Post-dredging monitoring data are critical to providing the documentation needed to validate the effectiveness of prescribed buffers, as well as monitor the stability of the borrow area over time particularly as it affects slope stability and edge effects. Many of these stability concerns are applicable to infrastructure (e.g., pipelines, platforms, and wellheads).

Because the monitoring campaign will be spatio-temporal, it is recommended that a similar data management system be used to represent and consult the gathered data. This will allow the user in decision taking and analysis of buffer changes through time and space.

9.7 Archaeological Resource Report Requirements

Consideration should be given to additions to the current MMS archaeological resource report requirements. Suggested additions reflect previous recommendations for equipment, survey methodology and data management and storage. Recommended for inclusion are:

- Georeferenced magnetic contour maps of the survey area;
- Georeferenced contours of all potentially significant anomalies;
- Detailed high-resolution sonar images of all anomalies;
- Georeferenced multibeam mosaics of the survey area bottom surface;
- Georeferenced GIS coverages for all report data sets;
- Digital copies of the final report document; and
- Georeferenced 3-D stratigraphic models of relic landforms identified as potential locations for prehistoric sites.

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