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TECHNICAL REPORT

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MUNITIONS RESPONSE REMEDIAL INVESTIGATION/FEASIBILITY STUDY GUIDANCE

By
NAVFAC Munitions Response Workgroup

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14. ABSTRACT

This guidance document includes an overview of the U.S. DON MRP, the regulatory framework governing investigations, and response actions under the MRP. In addition, the roles and responsibilities of key personnel and offices under the MRP are discussed. The focus of this guidance document is the RI/FS phase. Chapters discuss scoping the Munitions Response RI/FS, Terrestrial and Underwater RIs, MEC/material potentially presenting an explosive hazard (MPPEH) Removal and Treatment Technologies, the FS, and the RI/FS Report.

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ACRONYMS AND ABBREVIATIONS

AAR	After-Action Report
ACOE	Army Corps of Engineers
AFCEC	Air Force Civil Engineer Center
AGC	Advanced Geophysical Classification
AOPC	Area of Potential Concern
AQAPS	Automated Quality Assurance Program System
ARAR	Applicable or Relevant and Appropriate Requirement
ATSDR	Agency for Toxic Substances and Disease Registry
ASV	Autonomous Surface Vehicle
ATV	All-Terrain Vehicle
AUV	Autonomous Underwater Vehicle
BERA	Baseline Ecological Risk Assessment
BCT	BRAC Cleanup Team
bgs	Below Ground Surface
BHHRA	Baseline Human Health Risk Assessment
BIP	Blow in Place
BMS	Bottom Mapping Sonar
BOSS	Buried Object Scanning Sonar
BRAC	Base Realignment and Closure
CAIS	Chemical Agent Identification Sets
CDC	Contained Detonation Chamber
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
CHE	CWM Hazard Evaluation
CIP	Community Involvement Plan
CLEAN	Comprehensive, Long-Term Environmental Action, Navy
CNO	Chief of Naval Operations
COC	Chemicals of Concern
CRREL	Cold Regions Research Engineering Laboratory
CSIR	Contractor Significant Incident Report
CSM	Conceptual Site Model
CTT	Closed, Transferring, and Transferred
CWM	Chemical Warfare Material
DDESB	Department of Defense Explosives Safety Board
DD	Decision Document
DERP	Defense Environmental Restoration Program
DFW	Definable Features of Work

DGM	Digital Geophysical Mapping
DGPS	Differential Global Positioning System
DIDSON	Dual-frequency Identification Sonar
DL	Detection Limit
DMM	Discarded Military Munitions
DNT	Dinitrotoluene
DoD	Department of Defense
DON	Department of the Navy
DQO	Data Quality Objective
DU	Decision Unit
DVL	Doppler Velocity Log
EC	Engineering Control
EFH	Essential Fish Habitat
EHE	Explosive Hazard Evaluation
EMI	Electromagnetic Induction
EO	Executive Order
EOD	Explosive Ordnance Disposal
EPA	United States Environmental Protection Agency
ER	Environmental Restoration
ERA	Ecological Risk Assessment
ERDC	Engineer Research and Development Command
ER,N	Environmental Restoration, Navy
ESA	Endangered Species Act
ESO	Explosives Safety Officer
ESQD	Explosives Safety Quantity-Distance
ESS	Explosives Safety Submission
ESTCP	Environmental Security Technology Certification Program
EXWC	Engineering and Expeditionary Warfare Center
EZ	Exclusion Zone
FDEMI	Frequency-Domain EMI
FEC	Facilities Engineering Command
FUDS	Formerly Used Defense Sites
FS	Feasibility Study
ft	Feet
GPO	Geophysical Prove-Out
GPS	Global Positioning System
GSR	Green and Sustainable Remediation
GSV	Geophysical System Verification
GW	Groundwater
HA	Hazard Assessment

HE	High Explosive
HFD	Hazardous Fragment Distance
HHE	Health Hazard Evaluation
HHRA	Human Health Risk Assessment
HMX	Cyclotetramethylene-Tetranitramine
IC	Institutional Control
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
IR	Installation Restoration
IRP	Installation Restoration Program
IS	Incremental Sampling
ISO	Industry Standard Object
ITRC	Interstate Technology & Regulatory Council
IVS	Instrument Verification Strip
KHz	Kilohertz
LAW	Light Anti-Armor Weapon
LBL	Long Baseline
LiDAR	Light Detection and Ranging
LUC	Land Use Control
MARCORSYSCOM	Marine Corps Systems Command
MBES	Multibeam Echosounder
MC	Munitions Constituent
MCS	Magnetic Classification System
MD	Munitions Debris
MDAS	material documented as safe
MDEH	material documented as an explosive hazard
MEC	munitions and explosives of concern
MEC HA	Munitions and Explosives of Concern Hazard Assessment
MFD	maximum fragment distance
MGFD	munition with greatest fragmentation distance
MHz	Megahertz
MI	multi-increment
MILCON	Military Construction
MMPA	Marine Mammal Protection Act
MMRP	Military Munitions Response Program
MPPEH	Material Potentially Presenting an Explosive Hazard
MPV	Man-Portable Vector
MRA	Munitions Response Area
MRP	Munitions Response Program
MRSPP	Munitions Response Site Prioritization Protocol

MRS	Munitions Response Site
MURS	Magnetic UXO Recovery System
mV	milliVolt
mW	milliWatt
NAVFAC	Naval Facilities Engineering Command
NAVSEA	Naval Sea Systems Command
NAWQC	National Ambient Water Quality Criteria
NC	Nitrocellulose
NCP	National Contingency Plan
NERP	Navy Environmental Restoration Program
NEW	Net Explosive Weight
NFA	No Further Action
NG	Nitroglycerine
NIRIS	Naval Installation Restoration Information Solution
nm	Nautical Mile
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOSSA	Naval Ordnance Safety and Security Activity
NOSSAINST	NOSSA Instruction
NPL	National Priorities List
NRL	Naval Research Laboratory
NSWC IHEODTD	Naval Surface Warfare Center Indian Head Explosive Ordnance Disposal Technology Division
NSWC PC MCM	Naval Surface Warfare Center, Panama City, Mine Countermeasures
O&M	Operation and Maintenance
OB	Open Burn
OP	Ordnance Pamphlet
ORR	Office of Response and Restoration
OSWER	Office of Solid Waste and Emergency Response
PA	Preliminary Assessment
PP	Post Processing
ppm	Part Per Million
PQO	Project Quality Objective
PWD	Public Works Department
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QASP	Quality Assessment Surveillance Plan
QC	Quality Control
QCP	Quality Control Plan
QSM	Quality Systems Manual

RAA	Remedial Alternatives Analysis
RAB	Restoration Advisory Board
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
RCWM	Recovered Chemical Warfare Materiel
RDX	Royal Demolition Explosive
RI	Remedial Investigation
ROD	Record of Decision
ROV	Remotely Operated Vehicle
RPM	Remedial Project Manager
RTK	Real Time Kinematic
RTS	Robotic Total Station
SAP	Sampling and Analysis Plan
SAR	Synthetic Aperture Radar
SAS	Synthetic Aperture Sonar
SDWA	Safe Drinking Water Act
SERDP	Strategic Environmental Research and Development Program
SNR	Signal to Noise Ratio
SOP	Standard Operating Procedure
SOW	Statement of Work
SRA	Screening Risk Assessment
SRT	Sustainable Remediation Tool
SUXOS	Senior UXO Supervisor
TBC	to be considered
TCRA	Time-Critical Removal Action
TDEMI	Time-Domain EMI
TNT	Trinitrotoluene
TOI	Target of Interest
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plan
UFP-QS	Uniform Federal Policy for Implementing Environmental Quality Systems
USACE	U.S. Army Corps of Engineers
USBL	Ultrashort baseline
U.S. EPA	United States Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USRADS	Ultrasonic Ranging and Data System
UXO	Unexploded Ordnance
UXOQCS	UXO QC Specialist
VSP	Visual Sample Plan

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INTRODUCTION

The purpose of this guidance document is to provide the framework for conducting a Munitions Response Remedial Investigation/Feasibility Study (RI/FS) for Navy and Marine Corps Munitions Response Sites (MRSs) under the Defense Environmental Restoration Program (DERP). The DERP was established in 1986 under the Superfund Amendments and Reauthorization Act, which mandated that the U.S. Department of Defense (DoD) follow the same cleanup regulations that apply to private entities. Through the DERP, DoD conducts environmental restoration (ER) activities at sites on active installations, installations undergoing Base Realignment and Closure (BRAC), and formerly used defense sites (FUDS). The Office of the Secretary of Defense provides oversight for the DERP; however, each military department is responsible for implementation.

The Department of the Navy (DON) implements activities under the DERP through the ER Program. The program's goal is to provide timely and cost-effective assessment, planning, and remediation of identified releases consistent with DERP requirements. The DON ER Program is organized into two primary program categories:

- **Installation Restoration Program (IRP)** – The IRP addresses releases of hazardous substances, pollutants, or contaminants that pose toxicological risks to human health or the environment.
- **Munitions Response Program (MRP)** – The MRP addresses releases of munitions and explosives of concern (MEC), defined as unexploded ordnance (UXO), discarded military munitions (DMM), and munitions constituents (MC), which pose explosives safety hazards and risks to human health or the environment. Note, if the only contaminant in the soil is MC in concentrations less than that which would make the soil explosive (see Naval Sea Systems Command (NAVSEA) Ordnance Pamphlet 5 [OP5], Vol. 1, paragraph 14-10.1 [1]), the MC may be addressed under the IRP or MRP. The DON uses the term MRP to refer to its munitions response program, whereas the U.S. Army uses the term "Military Munitions Response Program (MMRP)."

This guidance document includes an overview of the U.S. DON MRP, the regulatory framework governing investigations, and response actions under the MRP. In addition, the roles and responsibilities of key personnel and offices under the MRP are discussed. The focus of this guidance document is the RI/FS phase. Chapters discuss scoping the Munitions Response RI/FS, Terrestrial and Underwater RIs, MEC/material potentially presenting an explosive hazard (MPPEH) Removal and Treatment Technologies, the FS, and the RI/FS Report.

1.0 DON MUNITIONS RESPONSE PROGRAM

The MRP addresses both human and ecological, health and safety hazards from MEC, MPPEH, and MC. Only those ranges designated as other than operational are included under the MRP.

Areas where previous military-related activities (e.g., live-fire training and testing, disposal operations, etc.) were conducted are designated as MRS. MRSs under the MRP are defined as discrete locations within a munitions response area (MRA) that is known to require a munitions response (Figure 1-1). This could include identification of locations that have target features or vehicles, debris from munitions or other munitions related features such as craters.

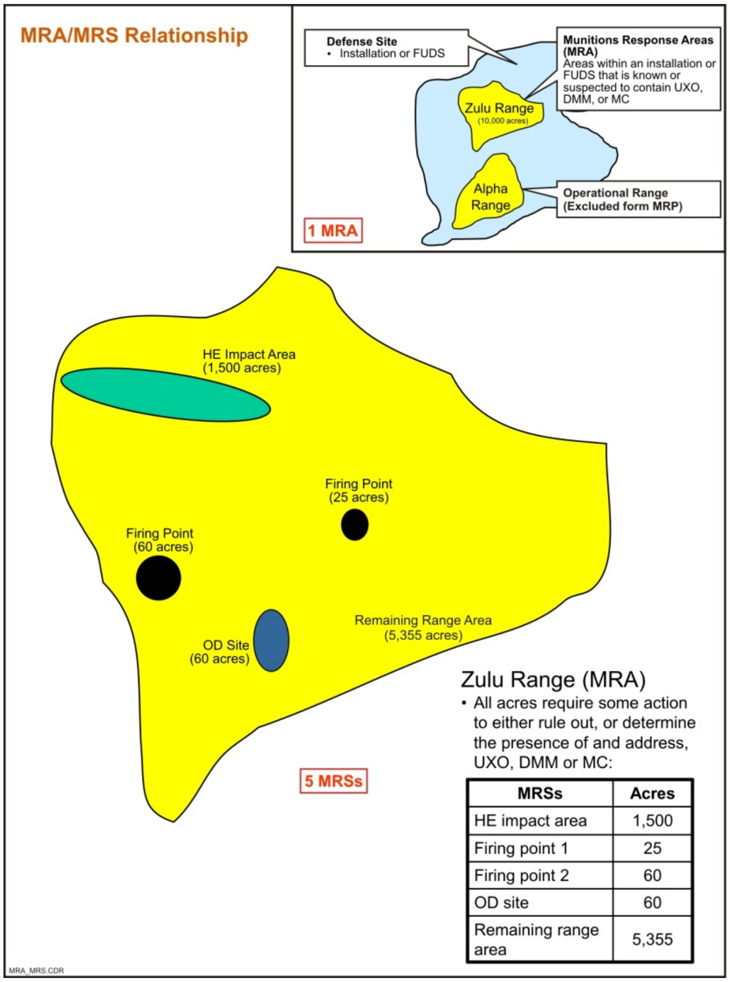

Figure 1-1. Munitions Response Area/Munitions Response Site Layout

Responses to address releases that are solely the result of an act of war are ineligible for the MRP. However, some sites may contain MEC/MPPEH from training and MEC/MPPEH due to combat operations. In that case, all of the MEC/MPPEH on the site regardless of release mechanism will be addressed by the MRP. When the DON is considering using the act of war ineligibility provision pursuant to Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) §9607(b)(2) the DON shall elevate the issue to the ASD(EI&E) for approval before proceeding with the exclusion.

The Office of the Secretary of Defense policy established a recovered chemical warfare materiel (RCWM) program with the Department of the Army as the executive agent. The Navy and Marine Corps have a small number of (RCWM) sites. This program account will fund: 1) the assessment of suspected munitions and other materials of interest (e.g., chemical agent identification sets-(CAIS)) to determine whether they are RCWM and 2) the destruction of RCWM. Overall DERP responsibilities for the sites will remain with the Navy/Marine Corps. Remedial Project Managers (RPMs) must coordinate activities on these Navy/Marine Corps RCWM sites with the Army Corps of Engineers via NOSSA N4 who have been designated as the primary interface. RPMs must identify any potential RCWM sites so that funding requirements can be coordinated with the Army. Cost to complete estimates and schedules for these sites should reflect the necessary coordination work and the assumption that the assessment and disposal of RCWM at the site will be funded by the Army.

1.1 Munitions Response Site Prioritization Protocol

The Munitions Response Site Prioritization Protocol (MRSPP) is the methodology developed by the DoD to assign a relative priority to MRSs for munitions response actions based on a site's overall conditions. The MRSPP provides a framework to use with stakeholders to determine the relative hazards/risks posed at each MRS. The MRSPP evaluates the primary hazards at a MRS posed by UXO, DMM, or MC. Three modules are used to evaluate the unique characteristics of each hazard type:

- The Explosive Hazard Evaluation (EHE) Module addresses explosive hazards posed by UXO, DMM, and MC in high enough concentrations to pose an explosive hazard;
- The CWM Hazard Evaluation (CHE) Module addresses hazards associated with the effects of CWM; and
- The Health Hazard Evaluation (HHE) Module addresses chronic health and environmental hazards posed by MC and incidental non-munitions related contaminants.

After the MRS is assigned a priority, the MRSs are sequenced for response actions. A MRS with higher relative hazards/risks should be addressed before a MRS with lower relative hazards/risks. However, other factors (e.g., community interests, value of land for development) may be considered in sequencing decisions.

The MRSPP should be completed at each MRS when there is sufficient data available to populate all the data elements in at least one of the three hazard modules (EHE, CHE, or HHE). In extremely rare circumstances, sufficient data for the MRSPP may not be available until the remedial investigation (RI) has been conducted.

Each MRS priority should be reviewed at least annually, and updated as necessary, to reflect new information. The MRSPP should be reapplied and priority re-evaluated for a MRS under the following circumstances:

- Upon completion of a response action that changes a MRS's conditions in a manner that could affect the evaluation under the MRSPP;
- When new information is available to update or validate a previous evaluation of a MRS;

- When the relative priority assigned to a MRS can be updated or validated, where that priority has been previously assigned based on evaluation of only one or two of the three hazard evaluation modules;
- Upon further delineation and characterization of a MRA into more than a single MRS;
- When new information is available to categorize any MRS previously assigned an alternative MRS rating of evaluation pending.

For tracking purposes, each MRS is assigned a unique MRS number and site name. The status of a MRS is tracked by Naval Facilities Engineering Command (NAVFAC) in the Navy "Normalization of Data" database MRSPP Module. Sites that do not have sufficient data available to score at least one of the three hazard modules should be ranked as "evaluation pending." Sites that have completed all required response actions (remedy-in-place/response complete) should be ranked as "no longer required." Sites may be ranked as "no known or suspected hazard" only when sufficient investigative evidence supports this determination.

More information for RPMs on implementing the MRSPP can be found in the *Munitions Response Site Prioritization Protocol Primer* [2].

1.2 Types of Munitions Response Sites

Munitions containing low- and high-explosives, propellants, pyrotechnics, incendiaries, etc. can be expected to be found at ranges where they were once used. Table 1-1 summarizes the types of MRSs, typical munitions used there, and possible categories of MEC that may be present. It is important to realize that munitions other than those typically employed at a range may sometimes be found there.

1.3 MEC Basics

MEC may be present in the MRS in the form of UXO, DMM or MC. Definitions of UXO, DMM, and MC can be found in Naval Ordnance Safety and Security Activity Instruction (NOSSAINST) 8020.15 (Series)/MCO 8020.10. UXO results from munitions which are prepared and fired but fail to function as designed (dud-fired). DMM may result from excess munitions being buried at firing points or bivouac areas rather than being properly turned into ammunition storage areas. MC may be released into the environment as a result of munitions firing (e.g., propellant at firing points) and a breached munitions casing which sometimes occurs upon incomplete filler detonation (low-order detonation), but can also be a result of mechanical breakup, deflagration, or corrosion after impact. OP5 provides concentrations by weight of primary and secondary explosive MCs in soil that pose an explosive hazard. Figure 1-2 is an example of a munition and the various locations where explosive materials may be present. Munitions have specific design features that can be obtained from various technical manuals (e.g. OP-1664).

Table 1-1. Summary of Typical Munitions and Possible MEC Present at MRSs

MRS TYPE	TYPICAL MUNITIONS USED	POSSIBLE CATEGORIES OF MEC
Small arms* range	Small arms ammunition	None
Grenade range	Hand and rifle grenades	UXO, DMM, MC
Artillery range	Medium and large caliber projectiles	UXO, DMM, MC
Bombing range	Bombs (including sub-munitions), medium and large caliber projectiles, rockets, guided missiles	UXO, DMM, MC
Air-to-Ground	Projectiles, rockets, guided missiles	UXO, DMM, MC
Ground-to-ground	Rockets and guided missiles	UXO, DMM, MC
Multi-use range	Small arms ammunition, projectiles, grenades, rockets, bombs	UXO, DMM, MC
Training/maneuver area	Small arms ammunition, signals, trip flares, other training devices	UXO, DMM, MC
Open burn/open detonation (OB/OD) area	Any and all types of military munitions	UXO, DMM, MC
Munitions manufacturing facility	The types of munitions manufactured at the facility, test ranges for lot acceptance testing, explosive residues in buildings and facility infrastructure, manufacturing rejects, test items, explosives in soils at concentrations high enough to pose an explosive hazard, groundwater (GW) contamination	UXO, DMM, MC
Storage area/transfer point	Various unused military munitions	DMM, MC
Firing point	Various unused military munitions	DMM, MC
Burial pit	Various unused military munitions	DMM, MC

*Ammunition without projectiles that contain explosives (other than tracers), that is .50 caliber or smaller, or for shotguns [1].

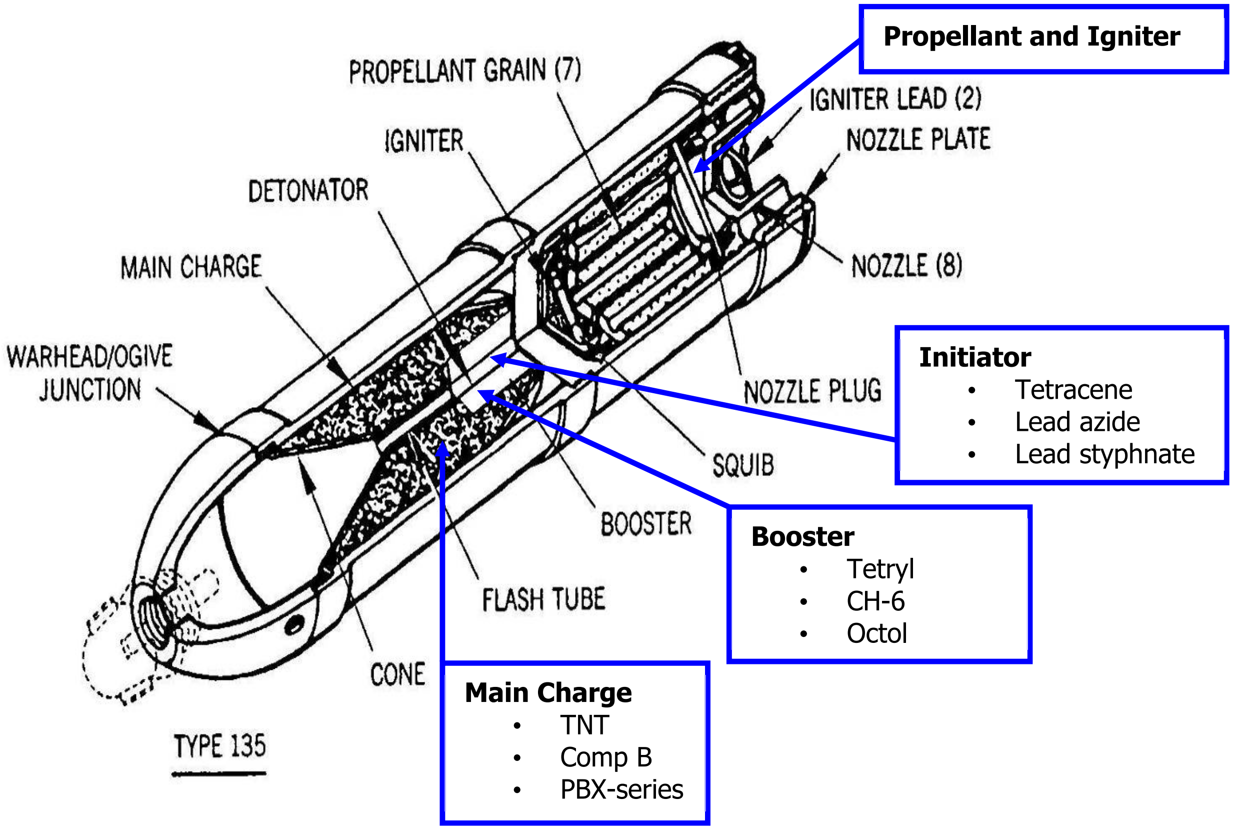

Figure 1-2. Typical Munitions Diagram

1.3.1 Explosives Safety

The explosives safety policies of the DON are directed at providing reliable ammunition and explosives in sufficient quantity to satisfy Navy and Marine Corps requirements in a safe manner. OP5 [1] provides explosives safety information and regulations to acquaint personnel with the characteristics and hazards of ammunition, explosives, and other related hazardous materials, and to prescribe standardized safety regulations for all operations where ammunitions and explosives are or are anticipated to be present. These policies require safe and efficient operating procedures while: (1) providing the maximum possible protection to personnel and property from the damaging effects of potential accidents involving DON ammunition and explosives; and (2) limiting the exposure of a minimum number of persons, for a minimum time, to the minimum amount of ammunition and explosives consistent with safe and efficient operations.

NOSSA Instruction (NOSSAINST 8020.15 (Series) [3]/MCO 8020.10 [4](for Marine Corps MRSs) assigns responsibility and establishes procedures and reporting requirements to enable NOSSA or the Marine Corps Systems Command (MARCORSYSCOM) to provide effective review, oversight, and verification of the explosives safety aspects of munitions responses. Prior to performing any intrusive on-site work, the RPM shall prepare an Explosives Safety Submission (ESS) for review and endorsement by NOSSA/MARCORSYSCOM and approval from the

Department of Defense Explosives Safety Board (DDESB). An ESS is a document that details how explosives safety standards in OP5 are applied to munitions responses. Additionally, it addresses how the project will comply with applicable environmental requirements related to the management of MEC and materials potentially presenting an explosive hazard (MPPEH). At a MRS where an ESS is required, no site operations can begin unless NOSSA/MARCORSYSCOM has reviewed and endorsed, and the DDESB has reviewed and approved the ESS. While awaiting DDESB review and approval, NOSSA (N4) is authorized to and may provide written, interim ESS approval. Interim ESS approval shall only be provided in extenuating circumstances, when written justification is provided by the RPM. Although such approval authorizes the RPM to proceed per the NOSSA-endorsed ESS, there is the risk that the DDESB may impose different or additional requirements.

The ESS shall be completed in accordance with NOSSAINST 8020.15 (Series)/MCO 8020.10, Enclosure (3)/MCO 8020.10 Appendix A "Guide for Preparing an Explosives Safety Submission." RPMs must ensure that their project schedules include adequate time for preparation, review, and approval of an ESS. This schedule needs to be clearly articulated with the entire project team, including regulatory agencies, stakeholders, and NOSSA/MARCORSYSCOM.

An ESS requiring NOSSA review must be submitted through the WebESS. The entire review process is managed within WebESS. After submittal to the WebESS the first level of review will be NAVFAC. All ESS submittals under the MR program are subject to NAVFAC review prior to NOSSA review. Review of an ESS at the NAVFAC level is optional for BRAC sites and at the discretion of the RPM. The review of other (e.g., Military Construction (MILCON) ESSs that do not impact a current and active MRP site are also optional and at the discretion of the RPM. The RPM will need access to the NOSSA website to access the WebESS. The WebESS user manual can be accessed from the WebESS.

For Marine Corps facilities the ESS should be drafted following MCO 8020.10 (current version). The ESS will be submitted to MARCORSYSCOM for action through the EES web portal per MCO 8020.10 Enclosure (1). RPMs will need to request an account in MAKE; email the explosives safety team and request permissions/roles on the EES portal. MARCORSYSCOM will assign a specific role, typically the same as the installation explosives safety officer (ESO that allows documents to be submitted and provides visibility of on-going projects. Access to the EES portal is limited to Marine Corps ESOs, NAVFAC RPMs (for munition response projects), and certain other individuals. New RPMs should contact the installation ESO for directions to get MAKE account.

An approved ESS from NOSSA/MARCORSYSCOM and DDESB is required for activities involving placement of explosives on a site, intentional physical contact with MEC or MPPEH, and all ground-disturbing or other intrusive activities in areas known or suspected to contain MEC or MPPEH. An ESS can be developed for a number of munitions response actions related to the RI/FS phase that may include but are not limited to MRS investigation/characterization; no further action; and time-critical removal actions (TCRA).

NOSSA/MARCORSYSCOM may determine that an ESS is not required for operations taking place in an area known or suspected to contain MEC or MPPEH when the likelihood of encountering them is low. To obtain NOSSA/MARCORSYSCOM determination that an ESS is not required, the RPM must complete and submit NOSSAINST 8020.15 (Series)/MCO 8020.10 Enclosure (2), "Explosives Safety Submission Determination Request". Information provided will allow NOSSA/MARCORSYSCOM to evaluate the site-specific conditions and the risk/hazard assessment (HA) and provide their findings in writing. An ESSDR for submittal to NOSSA will be submitted through the WebESS.

An After-Action Report (AAR) for completed munitions responses is a required feature of all DDESB-approved ESSs and shall be submitted within six months of the completion of the munitions response actions authorized by the ESS. The purpose of the AAR is to document that the explosives safety aspects of the selected response have been completed per the approved ESS. The AAR shall contain all of the elements listed in NOSSAINST 8020.15 (Series)/MCO 8020.10 Enclosure (5)/MCO 80201.10 "Guide for Preparing a Munitions Response Site After-Action Report".

RPMs should be aware that the Navy uses NOSSAINST 8020.15 (Series) and the Marine Corps uses MCO 8020.10 to assign responsibility and establishes procedures and reporting requirements for explosives safety. These procedures are currently identical except for the submittal process, but the Marine Corps retains oversight responsibility for munitions response aboard its installations. These procedures may not necessarily be the same in the future and RPMs will have to make sure the explosives safety requirements are specific to either the Navy or Marine Corps should there be any variation.

1.4 Regulatory Framework

The MRP is implemented under the DERP; therefore, the response actions follow the CERCLA response process as described in the National Contingency Plan (NCP). MRP response actions are normally categorized into investigations, removal actions, and remedial actions based on the severity of the safety hazard, level of detail, and scope.

Munitions response actions typically begin by site identification through completion of a preliminary assessment/site inspection. Through review of existing information and limited field data, the scope of the RI and the suitable level of response action and/or the immediacy of the response are determined. In situations where prompt action is required, the NCP allows for the implementation of a removal action (e.g. TCRA, non-time-critical removal action, etc.) to be performed in an expedited manner. If it is determined that remedial action is necessary, the FS is conducted which includes initial screening and detailed evaluation of remediation alternatives. Following completion of the RI/FS phase, the preferred alternative is documented in a Proposed Plan for public comments. All required remedial actions for the MRS are documented in the Record of Decision (ROD), followed by the remedial construction, implementation and completion phases. When RA Objectives are not designed to remove all MEC/MPPEH (including MC), technology limits the ability to remove all MEC/MPPEH, or when MEC/MPPEH or MC remain on site at levels that do not allow for unlimited use or unrestricted exposure (UU/UE), Land Use Controls (LUCs) are required to ensure the continued protectiveness of the remedy for the site's current or reasonably anticipated future reuse. The focus of this guidance document is the RI/FS phase of work under the MRP.

1.4.1 CERCLA RI/FS

The RI and FS for MRSs serves as the mechanism for collecting data to characterize site conditions, determine the nature and extent of the MEC and MC present, assess the hazard/risk to human health and the environment, and conduct treatability studies to evaluate the potential performance and cost of the treatment technologies that are being considered. In addition to evaluating various remedial alternatives using the United States Environmental Protection Agency (EPA) CERCLA nine criteria, explosives safety must also be taken into account during the FS evaluation using the nine criteria. Details regarding implementation of the RI/FS activities at MRSs are provided in Sections 4, 6, and 7 for terrestrial MRSs and Sections 5, 6, and 7 for underwater MRSs.

There are significant differences between a RI for a MRS, and a RI for a traditional Installation Restoration (IR) site. Unlike projects focusing on toxicity effects (human health or ecological) from chemical contamination (although this type of contamination may exist on the site), the primary objective of the MRS RI is to evaluate the potential explosive safety hazard at the site. The most common technique for evaluating a site with a potential subsurface explosive hazard is to perform a detailed geophysical survey with follow-on intrusive investigations of target anomalies to determine the extent of MEC contamination and to verify site boundaries. Munitions detection technologies that perform the detailed geophysical survey in the RI are discussed further in Sections 4 and 5. The ESS must be approved before intrusive RI work begins due to the likely contact with munitions. Also, once recovered, munitions cannot be reburied, so RPMs need to plan for management and disposal of MEC and munitions debris (MD) during the RI by their UXO contractor.

Reasonably anticipated future land use should be considered when scoping the RI activities and developing remedial options during the FS for MRSs. The current site ownership and plans for future site ownership are important considerations in evaluating the anticipated future land use, and the impact of any future change in land use on the protectiveness of the proposed remedy. EPA's *Reuse Assessment Guide* [5] provides guidance for determining future land use assumptions for CERCLA response actions. Additional guidance on this subject can be found in EPA's *Land Use in the CERCLA Remedy Selection Process* [6] and DoD's *Responsibility for Additional Environmental Cleanup after Transfer of Real Property* [7].

Figure 1-3 summarizes the various response actions, technologies and process options for MRSs. In general, remedial technologies for MRSs include options for detection, removal, and treatment of MEC. Treatment options will vary depending on the type of MEC to be addressed. This includes blow in place (BIP) with or without engineering controls (ECs), consolidated detonation, and contained destruction chamber. These options are discussed in detail in Section 6 of this guidance document.

Sampling techniques, analytical methods, and sample preparation considerations for MC are discussed in sections 4 for terrestrial MRSs and section 5 for underwater MRSs. At small arms firing ranges, treatment options include excavation with off-site disposal, soil washing/particle separation, soil stabilization, chemical extraction, asphalt emulsion batching-encapsulation, and phytoextraction/stabilization approaches. Energetic MC may potentially be treated with biological processes (e.g. in-situ bioremediation), physical processes (e.g. ion exchange), chemical processes (e.g. base hydrolysis), and thermal processes (e.g. low temperature thermal desorption). This guidance discusses treatment options for MC in section since information on these techniques is very similar to treatment of chemicals requiring treatment at Navy IR sites. More information on specific MC treatment can be found in section 6, the NAVFAC portal, SERDP/ESCTP, Interstate Technology & Regulatory Council (ITRC) website, EPA website, and the MR workgroup reference DVD.

1.4.2 RCRA Equivalents

For MRSs regulated under the Resource Conservation and Recovery Act (RCRA), RCRA provides for an equivalent sequence of activities under the corrective action program. Table 1-2 shows the parallel path for the CERCLA response action and RCRA corrective action programs, and the equivalent phase of work for each.

1.5 Roles and Responsibilities

Several parties may be involved throughout the RI/FS phase at MRSs. These parties include:

- The RPM;
- Federal, state, and local regulatory agencies;
- NOSSA/MARCORSYSCOM;
- DDESB;
- Naval Surface Warfare Center Indian Head Explosive Ordnance Disposal Technology Division (NSWC IHEODTD);
- Cognizant installation offices (e.g., explosive ordnance disposal [EOD], Explosives Safety Officer [ESO], Public Works Department [PWD] planner, Environmental Office);
- Navy and Marine Corps Public Health Center (NMCPHC);
- Other project stakeholders (e.g., Restoration Advisory Boards [RABs], property owners);
- The UXO contractor; and
- Third-party quality assurance (QA).

The roles and responsibilities of these various parties during the RI/FS are summarized in Table 1-3.

1.5.1 Regulatory Interface and Stakeholder Involvement

EPA and DoD seek to operate under the partnering concept. This concept facilitates open communication and information sharing among EPA, state, and federal facilities. Externally, partnering enhances and expedites the remedial activities required to reach a final cleanup at DoD installations. Internally, it provides an avenue for technology information sharing. This concept both enhances the working environment for the RPMs, and enhances information sharing and relationship building with the communities.

Although DoD is the lead agent at DoD installations, EPA plays a key role in providing oversight and input to the remedial decision-making process at National Priorities List (NPL) installations. EPA is the lead regulator for NPL installations. EPA signs Federal Facility Agreements and RODs for NPL installations. Ultimately, if DoD and EPA cannot agree on the remedy for a site and dispute resolution fails, EPA has the right to select the remedy. Therefore, it is important for DoD to work together with EPA throughout the ER process.

Additional agencies may also contribute to the remedial decision-making process at terrestrial and underwater sites. These agencies may include the National Oceanic and Atmospheric Administration (NOAA), the Office of Response and Restoration, National Marine Fisheries Service (NMFS), U.S. Army Corps of Engineers (USACE), U.S. Coast Guard, U.S. Fish & Wildlife Service, and State regulators.

Public and other stakeholder involvement in the MRP may include: participation in RABs; participation in public reviews; commenting on reports, Proposed Plans, and Decision Documents (DD), and input into land use planning for parcels being transferred from federal control.

The DON has found the use of RABs is an effective means of promoting stakeholder participation, including interaction with the community. The DON uses RABs as the primary mechanism to ensure that individuals within the community have access to information relevant to ER and have the ability to participate in the decision-making process. Promoting interaction with the community, regulators, and other stakeholders early in the process helps to ensure that remedial actions proposed by the DON gain stakeholder acceptance.

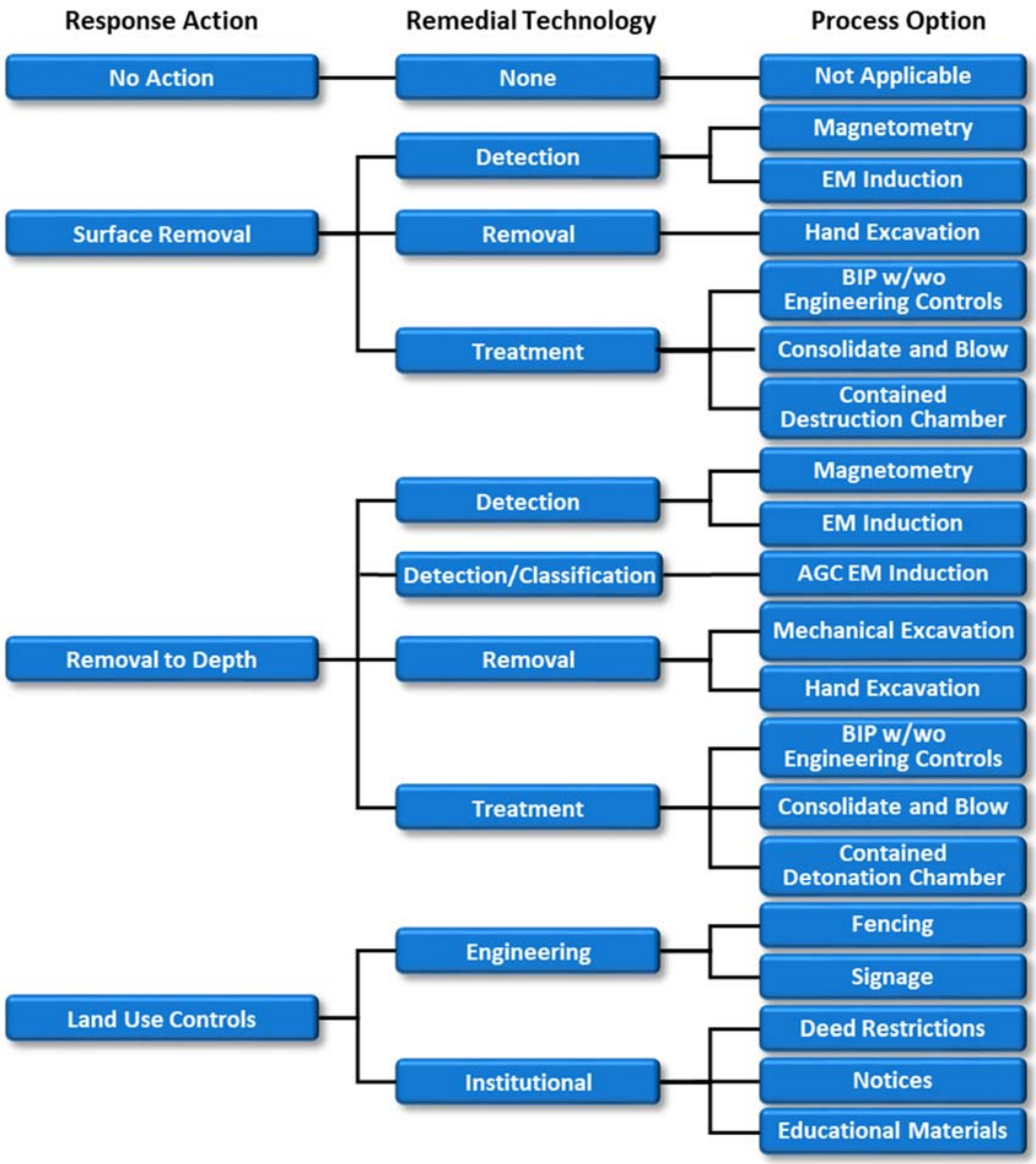

Figure 1-3. Example Response Actions for Munitions Response Sites

Table 1-2. Comparison of CERCLA Response Action and RCRA Corrective Action Programs

CERCLA RESPONSE ACTION	RCRA CORRECTIVE ACTION
Preliminary Assessment/Site Inspection • Preliminary assessment • Site inspection	RCRA Facility Assessment • Preliminary review • Visual site inspection • Sampling visit
Removal Action* • Non-time critical removal actions • Time critical removal actions • Emergency removal actions	Interim Measures* • Interim remediation • Temporary fixes • Alternate water supplies
Remedial Investigation • Site-specific data collection • Source characterization • Contamination characterization • Hydrogeological and climate factors • Potential routes of exposure • Extent of migration • Hazard/Risk assessment	RCRA Facility Investigation • Background data review • Environmental setting investigation • Sources characterization • Contamination characterization • Potential receptors characterization
Feasibility Study • Define objectives and nature of response • Develop alternatives • Conduct detailed analysis of alternatives	Corrective Measures Study • Identify and develop alternatives • Evaluate alternatives • Justify and recommend corrective measure
Remedy Selection • Select remedy that meets the nine National Contingency Plan criteria • Proposed Plan • Record of Decision	Remedy Selection • Select remedy that abates threat to human health and the environment • Statement of Basis
Remedial Design/Remedial Action • Design remedy • Perform remedial action • Perform operations and maintenance and monitoring	Corrective Measures Implementation • Develop implementation plan, program and community relations plan • Corrective measures design • Construction and implementation

*Note: Removal actions and interim measures may be implemented at any point during the response action or corrective action.

Table 1-3. Summary of Roles and Responsibilities

NAVFAC RPM	• Provides overall project management for the MRS and is involved in all aspects of the project including interagency relationships, funding, scheduling, investigation, design, and remedial action
ESO/PWD	• Approval/signature of ESS at active Navy installations • For BRAC sites, the ESO approval/signature may be completed by either the Navy Regional ESO or a technically qualified explosives safety official designated by the BRAC office, and the PWD planner's signature block may be completed by the BRAC Environmental Coordinator.
NOSSA	• Provides technical oversight, review, and verification of the explosives safety aspects of MRP response actions throughout the Navy. • Reviews, endorses, and forwards all ESSs and AARs to DDESB. • Determines whether an ESS is required. • Maintains a repository of munitions emergency response and response action notifications, ESSs and associated AARs, and some other MRP project-related documents.
MARCORSYSCOM	• Provides technical oversight, review, and verification of the explosives safety aspects of MRP response actions throughout the Marines Corps. • Reviews, endorses, and forwards all ESSs and AARs to DDESB. • Determines whether an ESS is required. • Maintains a repository of munitions emergency response and response action notifications, ESSs and associated AARs, and some other MRP project-related documents.
DDESB	• Provides oversight of the development, manufacture, testing, maintenance, demilitarization, handling, transportation, and storage of explosives, including CWM, on DoD facilities worldwide. • Ensures that safety is maintained during conduct of response actions by adhering to the requirement of DoD ammunitions and explosives safety standards. • Reviews and approves all ESSs and AARs forwarded by NOSSA/MARCORSYSCOM.
NSWC IHEODTD	• Provides technology and logistics management for the Joint Services EOD programs • Supports the Navy by providing independent government quality assurance for MRP projects • Provides technical support on projects as needed, for example installing an Instrument Verification Strip (IVS) for an underwater site.
EOD	• Each Service provides emergency response when unexpected MEC are encountered on their installation.[1] • Navy EOD responds to MEC found in the oceans and contiguous waters, up to the high water mark of seacoasts, inlets, bays, harbors, and rivers.[2]
Federal regulatory and other agencies	• Provides oversight of environmental cleanups and may be a resource owner. • On NPL sites, EPA has the authority to select a remedy if DoD and EPA cannot agree on the remedy and dispute resolution fails.
State regulators and local agencies	• Provides oversight of the environmental cleanup and may be a resource owner.
Project stakeholders (e.g., RABs, property owners, etc.)	• Participates in public reviews. • Provides comment on reports, proposed plans, and decision documents. • Provides input into land use planning for parcels being transferred.
UXO Contractor	• Provides technical support, data analysis, and reporting required during site characterization, investigation, remediation, and long-term management.
Third-Party QA	• Provides QA oversight of investigation and remedy implementation.
NMCPHC	• Provides human health risk assessment support, hazard/risk communication, and community involvement support • Provides toxicological support on chemicals that do not have an existing toxicity value, as well as on emerging contaminants and unregulated chemicals

[1] The Army is responsible for providing all off-installation explosives or munitions emergency responses:

East of the Mississippi:	West of the Mississippi:
52nd Ordnance Group (EOD)	71st EOD
Location: Fort Campbell, KY	Location: Fort Carson, CO
Phone: 270-798-7173	Phone: 719-526-2528

[2] The Navy is responsible for providing all underwater explosives or munitions emergency responses as well as providing all on-installation explosives or munitions emergency responses:

East of the Mississippi:	West of the Mississippi:
COMEODGRUTWO	COMEODGRUONE
Location: NAB Little Creek, VA	Location: NAB Coronado, CA
Phone: 757-462-8452	Phone: 619-522-3361

2.0 RI/FS POLICIES AND GUIDANCE

This section presents DoD and DON policy and guidance related to UXO management principles and the RI/FS process as it is applied to MRSs.

2.1 DoD and DON

2.1.1 DoD and EPA UXO Management Principles

The DoD and EPA developed a set of management principles in 2000 to address UXO at closed, transferring, and transferred (CTT)[2] ranges[8]. Many CTT ranges have been or will be transferred to the public domain. DoD and EPA agree that human health, environmental and explosive safety concerns at these ranges need to be evaluated and addressed.

To address specific concerns with respect to response actions at MRSs, DoD and EPA agree to the following general UXO management principles:

- DoD will conduct response actions when necessary to address explosives safety and risk to human health, and the environment. DoD and the regulators must consider explosives safety in determining the appropriate response actions.
- DoD is committed to communicating information regarding explosives safety to the public and regulators to the maximum extent practicable.
- DoD and EPA agree to attempt to resolve issues at the lowest level. When necessary, issues will be raised to the appropriate level at headquarters. This agreement should not impede an emergency response.
- The legal authorities that support site-specific response actions include CERCLA, as delegated by Executive Order (EO) 12580 and the NCP, particularly NCP §300.410 and §300.415; the DERP; and the DDESB. In addition, per DDESB, approved ESSs are required for TCRAs, non-time critical removal actions, and remedial actions involving explosives safety hazards, particularly UXO.
- A process consistent with CERCLA and these management principles will be the preferred response mechanism used to address UXO. Where this process is followed, it is expected to also meet any applicable RCRA corrective action requirements.
- These principles do not affect federal, state, and tribal regulatory or enforcement powers or authority concerning hazardous waste, hazardous substances, pollutants or contaminants, including imminent and substantial endangerment authorities; nor do they expand or constrict the waiver of sovereign immunity by the United States contained in any environmental law.

[2] Note that CTT is old terminology that was used before the establishment of the MRP and its terminology, including MRS.

The DoD and EPA agree that the goal of the RI is to collect adequate site characterization data at each MRS in order to understand the conditions, make informed risk management decisions, and conduct effective response actions. Site-specific project quality objectives (PQOs) and QA/quality control (QC) approaches are necessary to define the nature, quality, and quantity of information required to characterize each MRS and to select appropriate response actions. These PQOs and QA/QC approaches should be developed through cooperation among the various governmental departments and agencies involved at a MRS.

A permanent record of the data gathered to characterize a site during the RI and a clear audit trail of pertinent data analysis and resulting decisions and actions are required. To the maximum extent practicable, the permanent record shall include sensor data that are digitally recorded and geo-referenced. Exceptions to the collection of sensor data that are digitally recorded and geo-referenced should be limited primarily to emergency response actions or cases where it is not practical. The permanent record shall be included in the Administrative Record, and appropriate notification regarding the availability of this information shall be made to the regulatory agencies, public, and other stakeholders.

Discussions with local land use planning authorities, local officials and the public, as appropriate, should be conducted as early as possible in the response process to determine the reasonably anticipated future land use(s). These discussions should be used to scope efforts to characterize the site, conduct risk assessments, and identify appropriate response(s) for evaluation in the FS. LUCs contemplated as part of a remedial action must be clearly defined, established in coordination with affected parties (e.g., in the case of BRAC property, the prospective transferee), and enforceable. Final LUCs for a MRS should be considered as part of the development and evaluation of response alternatives using the nine criteria established under CERCLA regulations (i.e., NCP), and supported by site characterization data adequate to evaluate the feasibility of reasonably anticipated future land uses.

In addition to being a requirement when taking response actions under CERCLA, public involvement in all phases of the MRS response process is crucial to effective implementation of a response. Public involvement programs related to management of response actions at a MRS should be developed and implemented in accordance with DoD and EPA removal and remedial response community involvement policy and guidance.

2.1.2 DoD Policy on Advanced Geophysical Classification

The DoD developed the munitions response advanced geophysical classification (AGC) process to improve the efficiency of cleaning up munitions and focus resources on potential explosives safety risks at MRSs. To ensure quality data, the DoD has established the DoD Advanced Geophysical Classification Accreditation Program (DAGCAP) to accredit organizations that use AGC at MRSs. The DAGCAP is modeled after the laboratory accreditation program. The MRP now has several contractors that have been granted accreditation to perform AGC on MRSs. These companies have been assessed to International Organization for Standardization Organization/International Electrotechnical Commission 17025:2005 and the requirements of the DoD Quality Systems Requirements for AGC (DoD QSR V1.0). The DoD Components shall use only accredited UXO Contractors on their MRSs when performing AGC. The list of currently accredited contractors who can perform AGC can be found at the http://www.denix.osd.mil/mmrp.

2.1.3 DON Munitions Response Policy in OP5

It is the policy of the DON to maintain an effective and aggressive ordnance safety program. Adherence to the instructions and regulations contained in NAVSEA OP5, "Ammunition and Explosives Safety Ashore" [1] provides a continuing, aggressive accident prevention program throughout all commands where military or civilian personnel are stationed or employed and ordnance equipment, ammunition, and explosives are used. Chapter 14 of NAVSEA OP5, Vol 1 [1], establishes criteria to protect people and real property from explosive hazards associated with real property known or suspected to contain MEC or MPPEH, and munitions responses to MEC and/or MPPEH.

In accordance with OP5, the DON shall use the most appropriate technologies available to detect and remove anomalies that can indicate the presence of MEC and/or MPPEH, consistent with the current, determined, or reasonably anticipated future land use. Munitions response actions for change of use must be compatible with explosive hazards known or suspected to be present. When MEC and/or MPPEH cannot be removed to the degree necessary to safely allow the current, determined or anticipated future land use, the land use must be changed or restricted accordingly.

Real property known or suspected to contain MEC and/or MPPEH will not normally be transferred or leased from DON control until a munitions response consistent with the determined or reasonably anticipated land use has been completed. However, if the DON does not control the land and the imposition of a LUC is not possible (such as transferred, non-FUDS sites), the property owner and, if known, any tenants, must be provided written notification of the potential residual explosive hazards and the risks inherent in any use of property that is inconsistent with those hazards.

2.1.4 UFP-QAPP

The Uniform Federal Policy for Quality Assurance Project Plans (UFP-QAPP) is the product of an extensive collaborative effort by management- and working-level personnel from EPA, DoD, and the U.S. Department of Energy. It was created to address the real and perceived inconsistencies and deficiencies in data quality that result in greater costs, time delays, and the potential for response actions that result in unaddressed risk. The UFP-QAPP employs a process approach designed to encourage a level of detail consistent with the scope and complexity of the project. It is a tool that can be used for many different projects and its use can promote cost-effectiveness. EPA has issued a directive and guidance requiring EPA Regions to use the UFP-QAPP at federal facilities involving CERCLA, RCRA and Brownfield-type projects. The DoD has also requested that all DoD Components implement the UFP-QAPP for all DoD environmental projects, including those within the MRP. Therefore, RPMs and state regulators are encouraged to become familiar with the requirements of these documents and understand how they can impact their MRP projects.

The QAPP guidance uses a series of worksheets, available in the NAVFAC QAPP guidance, to guide the development of the comprehensive QAPP. The worksheets in the QAPP Workbook serve as a format for project planning from basic project administrative information, through the establishment of project objectives and detailed data quality objectives (DQO; requirements), to highly detailed quality inspections and analysis of data usability. Additional discussion regarding the use of the UFP-QAPP within the MRP is provided in Section 3.3.1.

Environmental sampling and testing must be performed in accordance with the UFP-QAPP and the *DoD Policy and Guidelines for Acquisitions Involving Environmental Sampling or Testing* [9]. This DoD policy establishes procedures and responsibilities regarding the implementation of minimum quality systems performance standards for environmental sampling or testing services procured by or on behalf of the DoD. Contractor quality systems documents collectively shall specify the QA responsibilities of the contractor. Quality systems documentation to be provided by the contractor will include one or more of the following:

- Documentation of the organization's quality system (usually called a Quality Management Plan) in accordance with the Uniform Federal Policy for Implementing Environmental Quality Systems (UFP-QS)
- Documentation of project-specific QA and QC activities (usually called a QAPP) in accordance with the UFP-QAPP
- Documentation of the laboratory quality system in accordance with the DoD Quality Systems Manual (QSM) for Environmental Laboratories [10]

Projects performing a terrestrial MR RI/FS for MEC utilize the "UFP QAPP Munitions Response QAPP Toolkit Module 1: Remedial Investigation (RI)/Feasibility Study (FS) Final, December 2018".

Section 3.3.1 in the RI/FS scoping chapter discusses the UFP-QAPP in more detail and the development of MEC and MC QAPPs.

2.1.5 DERP Manual

The DERP Manual [11] implements policy, assigns responsibilities, and provides guidance and procedures for managing the DERP. The DERP manual requires the DoD Component to consider the remedial alternatives that will address the potential explosive and chemical agent hazards associated with MEC and CWM known or suspected of being present in the planning of the site characterization conducted during an RI at a MRS. During the RI planning process, the DoD Component shall coordinate as appropriate with Federal and State environmental regulators, Indian tribal governments, local officials, and members of the public. During the FS, the DoD Component shall develop, screen, and evaluate remedial alternatives in detail; assess the performance of remediation options; and present such information so the decision maker can select a permanent solution that is protective of human health and the environment and attains or waives any applicable or relevant and appropriate requirements (ARAR)s. In the FS, the DoD Component must consider at least three alternatives: no action, action to remediate the site to a condition that allows unlimited use and unrestricted exposure (UU/UE) condition, and action to remediate the site to a protective condition that requires land use restrictions (i.e., LUCs or exposure controls).

2.1.6 NERP Manual

The Navy Environmental Restoration Program (NERP) Manual [12] applies to all DON ER sites on active and BRAC installations in the United States. The NERP Manual is a tool for RPMs that summarizes the organization and responsibilities of DoD and DON offices. It provides terminology and procedures used in implementing the ER program. The manual discusses funding eligibility, priority setting, reporting, and information management systems. It is meant to be a comprehensive reference for the DON user to properly identify, investigate, and select protective and cost-effective remedies for ER program sites.

Information provided in Chapters 8 and 12 of the NERP Manual is relevant to the topics discussed within this guidance document. Chapter 8 discusses the purpose of the RI/FS and process for completing this work at ER sites. Topics include the RI/FS scoping, RI site characterization, risk assessment, RI report, development of the remedial action objectives (RAOs) for the FS, identification and screening of remedial alternatives, detailed analysis of alternatives, and the FS report.

Chapter 12 discusses the MRP and response actions at MRSs. It provides RPMs with basic information, resources, and necessary tools to understand and to begin executing and managing MRP projects. It also outlines specific differences between the MRP and the traditional IRP. Information provided in Chapter 12 of the NERP Manual includes preparing the ESS, scoping the RI/FS, completing of Munitions and Explosives of Concern Hazard Assessments (MEC HAs), discussion of munitions detection technologies, and MRP QA.

2.1.7 NAVFAC Business Management System Forms

The NAVFAC Business Management System form is designed as a tool to obtain access to applicable information resources and enable an understanding of the process followed to perform various aspects of projects. The NAVFAC Business Management System includes 10 sets of MRP-related forms, including one of each for the RI and the FS at MRSs. Each of the Business Management System forms for the MRP-related RI and FS contain the process steps for completing this phase of work. A description of the associated procedure, and resources available for each process step is in Table 2-1. The table summarizes the process steps that are presented for the MRP-related RI and FS.

Table 2-1. Summary of Process Steps for Implementation of MRP RI/FS

	RI	FS
1	Form the RI Project Team	Form the FS Project Team
2	Implement Contract Action for the RI	Obtain Contract Support for the FS
3	Establish an Information Repository and Administrative Record File	Ensure Sufficient Data are Available for the FS
4	Identify and Scope the RI Goals and Objectives	Develop RAOs
5	Prepare RI Work Plans to Document Objectives, Methods and Procedures	Develop a List of Remedial Alternatives
6	Prepare ESS	Evaluate Remedial Alternatives
7	Conduct RI Field Work	Prepare MRP FS Report
8	Evaluate and Interpret RI Data	Determine Next Steps
9	Prepare, Review and Revise the RI Report and AAR	--
10	Determine Next Steps	--

2.1.8 NAVFAC ESS and AAR Pre-Submittal Review Requirements

NAVFAC policy requires a QA review of draft ESS and AAR documents by NAVFAC Echelon III personnel prior to NOSSA review. The review process is intended to provide a NAVFAC-wide, uniform QA check for explosive safety documents at MRSs, provide Echelon IV/III/II with awareness of explosive safety issues and successes, and enable process improvements relative to explosive safety documents.

This process is mandatory for ER,N MRSs. This process does not apply to BRAC explosive safety documents unless explicitly requested. This process does apply to MILCON/construction projects when they occur on MRSs. Additional details on how this review is integrated into WebESS are provided in *NAVFAC WebESS Pre-Submittal Review Process Guidance* [13]

2.1.9 Optimization Policy for DON ER Program Sites

The *Policy for Optimizing Performance and Sustainability of Remedial and Removal Actions at all DON Environmental Restoration (ER) Program Sites* [14] mandates that the following actions be performed on DON ER Program sites:

- Ensure that remedial actions are optimized for cost and performance throughout the ER process;
- Incorporate green and sustainable remediation (GSR) into the optimization process;
- Perform a Remedial Alternatives Analysis (RAA) to ensure sites have been effectively optimized;
- Ensure the use of SiteWise^{TM} tool in the FS; and
- Report optimization and GSR efforts in NORM.

The optimization policy indicates opportunities to improve performance and to evaluate GSR practices. It shall be considered and implemented throughout all phases of remediation. This is regardless of the regulatory framework under which cleanup may occur. The concept of GSR emphasizes and promotes consideration of sustainability practices throughout the entire remedial process, including the remedy, evaluation, and selection. It is anticipated that the greatest opportunities to improve performance and reduce the footprint of the DON ER Program are associated with the remedy selection process. Therefore, special emphasis is placed on addressing optimization and sustainability during the remedy selection. In accordance with the optimization policy, a two-phase approach shall be used for remedy evaluation and selection documents (i.e., FS, Engineering Evaluation/Cost Analysis, Corrective Measures Study, or Corrective Action Plan).

Completion of the RAA is one of the optimization steps. The appropriate time to conduct a third-party RAA review in the FS process is when remedial alternatives have been identified and screened but prior to detailed evaluation. The RAA review is a fast-tracked optimization review of the remedial alternatives that will ultimately be evaluated in the FS. It provides an opportunity to optimize the remedial alternative evaluation process, looking at the alternatives selected for further review and potentially considering additional alternatives not selected. Past experience has shown that an optimization review at this stage can save time and cost by avoiding the need to back up and re-consider alternatives after the full draft FS has been submitted for review. Details regarding the process required to complete the RAA and the RAA template are provided in the final RAA guidance, which was issued in April 2012 [15]

As the second step, each alternative carried forward into the FS (or other remedy evaluation document) must then be optimized in accordance with the *DON Guidance for Optimizing Remedy Evaluation, Selection, and Design* [16]. As part of this step, remedy footprint analysis using the SiteWise™ tool shall be conducted in accordance with *DON Guidance on Green and Sustainable Remediation* [17]. Other tools, such as the Air Force Center for Engineering and the Environment (AFCEE) Sustainable Remediation Tool (SRT™) or similar GSR tools can also be used but they can only be used in conjunction with or after an analysis using the SiteWise™ tool has first been performed. The GSR metrics evaluated during this analysis can be incorporated into the review of the CERCLA criteria during the FS. More discussion of the GSR procedures and integration of the analysis into remedy selection documents is provided in the DON GSR guidance.

2.1.10 Chief of Naval Operations Policy and Guidance

The following subsections summarize Chief of Naval Operations (CNO) policy and guidance as it relates to MRP RI/FS projects. This includes policy on identifying and addressing underwater MRSs, and CNO policy on conducting ecological and human health risk assessments (HHRAs). The risk assessment process can be applied to MCs identified at MRSs, however, MEC is evaluated through a separate HA. The HA process is discussed further in Section 2.2.

2.1.10.1 Navy Underwater MRP Site Policy

The Navy has developed policy for underwater MRSs [18]. Underwater MRSs are considered shallow water areas where munitions releases are known or suspected to have occurred, where Navy actions are responsible for the release, and where munitions are covered by water no deeper than 120 feet (ft). Note that MRS located in waters between high and low tides will be considered terrestrial sites. Sites meeting the above criteria will follow the underwater MRP site policy, with the following exceptions:

- A site that is part of, or associated with, a designated operational range (terrestrial or water range);
- A designated water disposal site;
- A FUDS;
- A result solely of combat operations;
- A maritime wreck; and
- An artificial reef.

Sites that can be 'reasonably' dewatered, such as a test pond, or other controlled structure can be considered a terrestrial site, when it is feasible and cost effective to conduct dewatering operations to support the MR program.

Wetland areas, rivers, creeks, streams or other areas where water intrusion cannot be controlled, or would complicate access to study, identify or remediate munitions should also be considered a water site.

Cleanup at identified underwater MR sites is based on hazard and risk determinations. Existing risk assessment guidance is applicable for MCs identified at an underwater MR site. Sections 2.1.10.2 and 2.1.10.3 discuss guidance on ecological and human health risk assessment for MCs.

Explosive hazards must be assessed on a site-specific basis; there is no standard model for assessing underwater explosive hazards. More information on HAs is presented in Section 2.2. and 5.4.2.

2.1.10.2 Ecological Risk Assessment

On 5, April, 1999, the CNO issued policy for conducting ecological risk assessments (ERAs) at ER project sites. The purpose of this policy is to provide clarification on the manner in which ERAs are to be implemented for the Navy. The policy applies to all ER activities performed under CERCLA. It was developed to be consistent with the requirements of EPA and ERA guidance.

In accordance with the policy, Navy RPMs must ensure that ERA studies provide information that is relevant to the remedial decision-making process. The ERA must be designed to allow for a risk determination and support a risk management decision. The policy identifies a three-tiered process for estimating ecological risks and evaluating the effectiveness and potential ecological impacts of remedial alternatives, including (1) screening risk assessment (SRA), (2) baseline ecological risk assessment (BERA), and (3) evaluation of remedial alternatives. It is important to note the tiered approach identified in this policy is a process and not a specific risk assessment method. It provides a logical, sequential process for designing and conducting ERAs and reaching defensible risk management decisions. The policy also stresses early and frequent interactions among the RPMs, risk assessors, and regulators in order to avoid unnecessary costs, effort, and surprises.

The Navy Guidance for conducting ERA web page contains more information regarding the ERA policy, including the following topics:

- **Regulatory Basis for ERA** – Provides an overview of the regulatory requirements for conducting ERAs.
- **Navy Natural Resource Responsibilities** – Defines a Natural Resource Trustee, addresses the Navy's role as a Trustee, and presents an overview of the Natural Resource Damage Assessment process.
- **Navy Policy for ERA** – Presents the CNO ERA policy and describes the three-tiered process identified in the policy.
- **The ERA Process** – Provides information to aid in the design and conduct of ERAs and ecological impact evaluations as identified in Tier 1 SRA, Tier 2 BERA, and Tier 3 Evaluation of Remedial Alternatives of the CNO ERA Policy.
- **Site Closeout Process** – Provides information on how to move a site from the ERA process to final site closure, including closure procedures and closeout decision documentation.
- **Issue Papers** – Provide information on a range of ERA-related topics, ranging from probabilistic risk assessment to risk characterization.
- **Tools and Analytical Methods** – Lists and briefly describes ERA tools (e.g., models, statistical packages) and methods (e.g., toxicity tests).
- **Case Studies** – Examples of Navy ERAs can be found on the ERA guidance Web page.

2.1.10.3 Human Health Risk Assessment

On 12, February, 2001, the CNO issued policy for conducting HHRAs for ER project sites. The primary goal of the policy was for Navy HHRAs to follow a three-tiered risk assessment process. Risk assessment is an integral part of the remedial response process defined by CERCLA and the NCP, and is a key step in the ER process because it provides context for all of the information that is generated during the investigation process. Risk assessment results are used to evaluate site concentrations to determine if the risks are significant, whether or not further investigation or other actions are appropriate, and to help determine cleanup levels for remediating a site, consistent with EPA's *Risk Assessment Guidance for Superfund: Human Health Evaluation Manual (Part A)* [19].

The tiered approach presented in the CNO policy ensures that the level of effort expended to evaluate sites is commensurate with the magnitude and complexity of the site-specific issues. At relatively simple sites, risk-based screening (Tier I) can be used to evaluate the potential risks. At complex sites (e.g., sites with multiple chemicals of concern (COC) or exposure pathways), a baseline human health risk assessment (BHHRA) (Tier II) can be performed to evaluate site-specific exposure scenarios and receptors. The human health risks associated with remedial alternatives are evaluated in Tier III.

In addition to the three-tiered approach, the policy identifies the following exit criteria that should be used to determine whether or not a site can exit the HHRA process:

- **Incomplete Exposure Pathways** – If chemicals present on site are not accessible to humans, then there is no possibility for human exposure, no risk, and the site can exit the HHRA process.
- **Background** – If there are no chemical concentrations present on site that are greater than background concentrations, then the site can exit the HHRA process.
- **Risk-Based Screening** – If there are no chemicals present on site that are greater than default risk-based regional screening levels in Tier IA or site-specific risk-based screening concentrations in Tier IB, then the site can exit the HHRA process.
- **BHHRA** – If a BHHRA determines that the chemicals present at a site pose an acceptable risk, then the site can exit the HHRA process.

More information regarding the HHRA policy and process can be found in the *U.S. Navy Human Health Risk Assessment Guidance* [20].

2.1.11 Community Involvement

Community involvement promotes communication between the public and the DON concerning the status of remediation at installations. Public involvement is required by CERCLA provisions at specific stages of response actions (42 USC Sections 9613 and 9617). Recognizing the importance of proactive community involvement, the DON's community involvement requirements are more comprehensive than the minimum CERCLA requirements. The DON responsibilities during the response action process include informing the community of any action taken, responding to inquiries, and providing information about any releases of hazardous substances.

The *Navy Environmental Readiness Program Manual* (OPNAV M-5090.1D, 10 January 2014) and *Marine Corps Environmental Compliance and Protection Manual* (MCO P5090.2A, 26 August 2013) provide public participation guidance. CERCLA requirements are discussed in Section 15.6.

As stated in OPNAVINST 5090.1D, DON public participation requirements are more comprehensive than the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). For example, DON requires a formal Community Involvement Plan (CIP) at all ER Program sites, whether or not they are NPL sites. Note that these plans were previously called Community Relations Plans. The CIP is a site-specific strategy for meaningful community involvement throughout the CERCLA cleanup process. CIPs are prepared and implemented on an installation-wide basis rather than for a specific ER action. The NERP manual provides additional guidance on community involvement.

2.2 MEC Hazard Assessment

The CERCLA response process includes the development of risk assessments appropriate to the requirements of a site, which guides decisions on further response actions and risk management decisions. However, the HHRA methodology was not designed to address MEC safety hazards at MRSs. There still is no standard consensus process for performing a BHHRA addressing exposure to MEC. The threats presented by MEC are different from those presented by chemicals/munitions constituents (MCs). MEC presents an acute hazard of direct physical injury resulting from the blast, heat, or fragmentation resulting from contact. The concept of chronic, long-term exposure does not apply to hazards posed by MEC.

Pending the development of consensus methods for assessing and quantifying hazards posed by MEC, project teams must develop site-specific approaches to assessing these hazards. Two different approaches are discussed in the following paragraphs.

The Munitions and Explosives of Concern Hazard Assessment Methodology [21] was developed by a multiagency workgroup as a tool to assist site managers and regulators in evaluating explosive safety hazards to people at MRSs, consistent with CERCLA and the NCP. The MEC HA allows a project team to evaluate the potential explosive hazard associated with a MRS, given current conditions and under various cleanup, land use activities, and LUC alternatives. The MEC HA is also designed to enhance communication of hazards within a project team, and between project teams and external stakeholders.

The MEC HA reflects the fundamental difference between assessing chronic environmental contaminant exposure risk and assessing acute MEC explosive hazards. An explosive hazard can result in immediate injury or death. Risks from MEC explosive hazards are evaluated as being either present or not present. If the potential for an encounter with MEC exists, the potential that the encounter may result in death or injury also exists. Consequently, if MEC is known or suspected to be present, a munitions response typically will be required. The munitions response may include further investigation, cleanup of MEC through a removal or remedial action, including LUCs, or LUCs alone.

The MEC HA addresses human health and safety concerns associated with potential exposure to MEC at MRSs under various site conditions. It does not directly address environmental or ecological concerns that might be associated with MEC. Nor does it address operational ranges, underwater sites, or CWM.

The MEC HA is conducted through the systematic planning process that guides environmental investigations. As such, it is designed to be a collaborative process that draws upon the collective understanding and expertise of a project team consisting of lead agency personnel, regulators, and stakeholders. The MEC HA is structured around three components of potential explosive hazard incidents:

- **Severity** - the potential consequences of the effect (e.g., death, injury) on a human receptor should a MEC item detonate.
- **Accessibility** - the likelihood that a human receptor will be able to come in contact with a MEC item.
- S**ensitivity** - the likelihood that a human receptor will be able to interact with a MEC item such that it will detonate.

Each of these components is assessed in the MEC HA by input factors having two or more categories. Each input factor category is associated with a numeric score that reflects the relative contributions of the different input factors to the MEC HA. The sum of the input factor scores falls within one of four defined ranges, called hazard levels. Each of the four hazard levels reflects attributes that describe groups of MRSs and site conditions ranging from the highest to lowest hazards.

The MEC HA allows a project team to assess MRSs on the most appropriate scale by dividing an MRS into subunits, if necessary. The MEC HA can be used to score a MRS several times to assess current conditions and the conditions expected after completion of different removal or remedial actions. It can also be used to assess different types of determined or reasonably anticipated future land use activities. It is important to remember that the MEC HA is not a quantitative measure of explosive hazard and that it does not answer the question of "How clean is clean". Project teams should also realize that the public may perceive that the lower the score, the better/more protective the remedy will be. This may result in the public wanting the lowest score from the methodology (e.g. subsurface removal). This can detract from a full consideration of the nine CERCLA criteria for remedy selection that would account for other things the methodology doesn't consider such as endangered species and the ecological damage that may occur from some remedies.

In January 2009, the Deputy Under Secretary of Defense for Installations and Environment (DUSD(I&E)) recommended that the DoD Components use and evaluate the MEC HA during a two-year trial period. In July 2011, the DUSD(I&E) extended the trial period until July 2013, because the MEC HA applies to the RI and FS phases, and too few MRSs had reached those phases by July 2011 to evaluate the tool.

In May 2013, ODUSD(I&E)/Environment, Safety, and Occupational Health Directorate (ESOH) issued a memorandum to the DoD Components requesting that their installation representatives complete the MEC HA Methodology Evaluation Form. The purpose of this evaluation was to document user experiences with the MEC HA Methodology and Workbook during the trial period. ODUSD(I&E) ESOH used this information to reconvene the TWG to address issues raised by the review. To date, no revised version of the MEC HA Methodology has been provided. The identified time period in the memorandum has passed, but the memorandum or a follow on memorandum rescinding the original memorandum has not been issued. If a project team chooses to use the MEC HA Methodology, they should complete the MEC HA Methodology Evaluation Form.

The ACOE is currently in a trial period of the "Study Paper: Decision Logic to Assess Risks Associated with Explosive Hazards, and to Develop Remedial Action Objectives for MRSs." The Navy is not currently trialing this paper. It should be noted that all MEC risks methodologies or processes developed to date are qualitative and therefore RPMs will have to rely on multiple lines of evidence to support the evaluation of risk and the need for remedial actions.

2.3 EPA RI/FS Policies and Guidance

EPA has developed policy and management guidance on how to proceed with cleanup of munitions and MC. The guidelines are designed to be used by EPA Regions for providing regulatory oversight where a DoD component will be conducting a munitions response action as the lead agency at locations other than an operational range.

The *Handbook on the Management of Munitions Response Actions (Interim Final)* [22] is used by field personnel and is currently being revised. Key topics discussed in this handbook include planning munitions response investigations, devising investigation and response strategies, detection technologies, and response technologies.

In addition to the handbook, EPA's Office of Solid Waste and Emergency Response (OSWER) has also issued the following two directives relevant to the MRP RI/FS process:

- OSWER Directive 9200.3-60, Recommendations for EPA Regional Offices on PAs and SIs for the DoD MMRP, April 5, 2010. The MRSPP was developed by DoD as the basis for assigning relative priorities for funding subsequent munitions response actions. This Directive indicates that when an MRS scores 1, 2, or 3 under the MRSPP, it may be appropriate for EPA to consider if a removal action is needed as a first step in the CERCLA response process.
- OSWER Directive 9200.1-101, EPA Munitions Response Guidelines, July 27, 2010. These guidelines discuss several types of response actions (e.g., assessments, investigations and cleanups) under the authorities of CERCLA, RCRA, and, where appropriate, response actions under other Federal environmental authorities, such as the Safe Drinking Water Act (SDWA). The guidelines may be useful in situations involving enforcement, permitting, and emergency or time critical actions where MEC/MC are involved.

Key topics discussed in these guidelines include:

- Sampling and analysis plan (SAP) structure and review process
- Site characterization procedures
- Statistical sampling tool applications and limitations
- Technology selection criteria
- Maintaining a permanent record of the geophysical survey
- Risk/HA for MEC/MC
- Early discussions of LUCs

- Use and evaluation of LUCs at an MRS

Additional general guidance from EPA related to implementation of the RI/FS phase of work under CERCLA include the following:

- EPA. 2000. A Guide to Developing and Documenting Cost Estimates during the Feasibility Study. EPA 540/R-00/002, OSWER 9355.0-75.
- EPA. 1990. The Feasibility Study: Detailed Analysis of Remedial Action Alternatives. OSWER 9355.3-01FS4.
- EPA. 1989. Getting Ready: Scoping the RI/FS. OSWER 9355.3-01FS1.
- EPA. 1989. The Feasibility Study, Development and Screening of Remedial Action Alternatives. OSWER 9355.3-01FS3.
- EPA. 1989. The Remedial Investigation, Site Characterization and Treatability Studies. OSWER 9355.3-01FS2.
- EPA. 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final. EPA 540/G-89/004, OSWER 9355.3-01.

3.0 RI/FS MANAGEMENT

The RI/FS process begins with forming the project team to ensure proper management and implementation of the RI/FS activities. The project team for implementing the RI/FS under the MRP will consist of the following:

- Executing activity (Facilities Engineering Command (FEC), BRAC Program Management Office, etc.);
- Installation environmental personnel;
- Navy contractor;
- NOSSA or MARCORSYSCOM;
- Regulators (Federal, state, and local environmental agencies);
- Other stakeholders (Federal land managers, Federally recognized tribes);
- Quality Assurance (NAVFAC, NSWC IHEODTD, third party contractor, or other); and
- NSWC Panama City (for underwater sites).

Public involvement is also an important component of the RI/FS process. Public involvement is typically accomplished through the RAB, where stakeholder groups meet on a regular basis to discuss ER progress and activities at a specific property. The RAB allows for an exchange of information with the community and offers the public an opportunity to influence clean-up decisions through discussion and providing input to decision makers. Engaging the stakeholders early and often will help minimize project delays by promoting communication to efficiently address any concerns from the project team.

Information provided in Section 3.1 of this guidance will assist the RI/FS project team in scoping the RI/FS under the MRP. RI/FS tools available for use by the project team are described, the typical RI/FS definable features of work (DFW) are identified, and methods for managing uncertainty in an MRP project are described. In addition, the EPA seven-step process for conducting the RI/FS is presented along with an explanation of the development, review, and stakeholder approval process for munitions response plans.

Generally, DON performs the RI phase concurrently and in an integrated manner with the FS. Integrating the development of the RI and FS is important to ensure that data obtained in the RI is appropriate to evaluate likely remedial alternatives during the FS. However, in some cases, the RI is completed with the objective being to support a hazard/risk management decision but not to support remedy development. In this case, if the RI determines that a remedy is necessary, a supplemental investigation can be performed as part of the FS.

3.1 Scoping the RI/FS

The entire project team (Navy, UXO contractor, NOSSA/MARCORSYSCOM, Naval Surface Warfare Center, Panama City, Mine Countermeasures [NSWC PC MCM] for underwater sites, installation environmental personnel, regulators and other stakeholders) should be involved in the RI/FS scoping process. The primary contracting mechanism for selecting the UXO contractor is the Comprehensive, Long-Term Environmental Action, Navy (CLEAN) contract through the FEC. Other contracting mechanisms are available, including NAVFAC Atlantic, Pacific and the Engineering and Expeditionary Warfare Center (EXWC). Each contract vehicle should be evaluated in terms of the remaining contract capacity and expiration, as well as the contract term and type (i.e., fixed price vs. cost-plus), in order to determine the most appropriate contracting mechanism. Contractor experience and performance indicators are important considerations in the UXO contractor selection process.

Project scoping, which involves the entire project team, is the best way to ensure a project meets the goals of the Navy and the stakeholders. It also ensures that the project needs are adequately defined. The penalty for ineffective planning is greater conflict and extensive reworking, which can be costly and time consuming. The best way to ensure that a project meets its goals is to have project planning meetings with all of the stakeholders (e.g., data users, data producers, decision makers) to discuss the project scope. Figure 3-1 presents a flow diagram outlining steps in the RI/FS scoping process.

Goals of RI/FS scoping include:

- Identify investigation area(s) and determine the reasonably anticipated future land use;
- Describe the type and content of studies needed to initiate response actions and determine the nature and extent of MEC/MC and associated hazard/risk;
- Determine if there is a need for remedial actions; and
- Determine appropriate response mechanisms and authorities.

Developing a mutual understanding of the above items among the project team and stakeholders is a key component of the RI/FS scoping stage. Several considerations should be discussed as part of the RI/FS scoping in order to achieve the RI/FS scoping goals. There must be a mutual understanding among the project team regarding the reasonably anticipated future land use, exposure unit areas, and MEC/MC initial hazard/risk screening results. An understanding of these items is key in developing the data needs of the RI. In addition, the reasonably anticipated future land use will determine potential future receptors and exposure routes which impact the HHRA, ERA, and HA, as well as the potential range of responses evaluated in the FS to address those risks/hazards. These items are the foundation for the project team to develop the investigation approach and objectives of the RI/FS.

During the RI/FS scoping process, potential technical limitations should also be identified, and the impact on the RI/FS process evaluated by the project team. Technical limitations may include

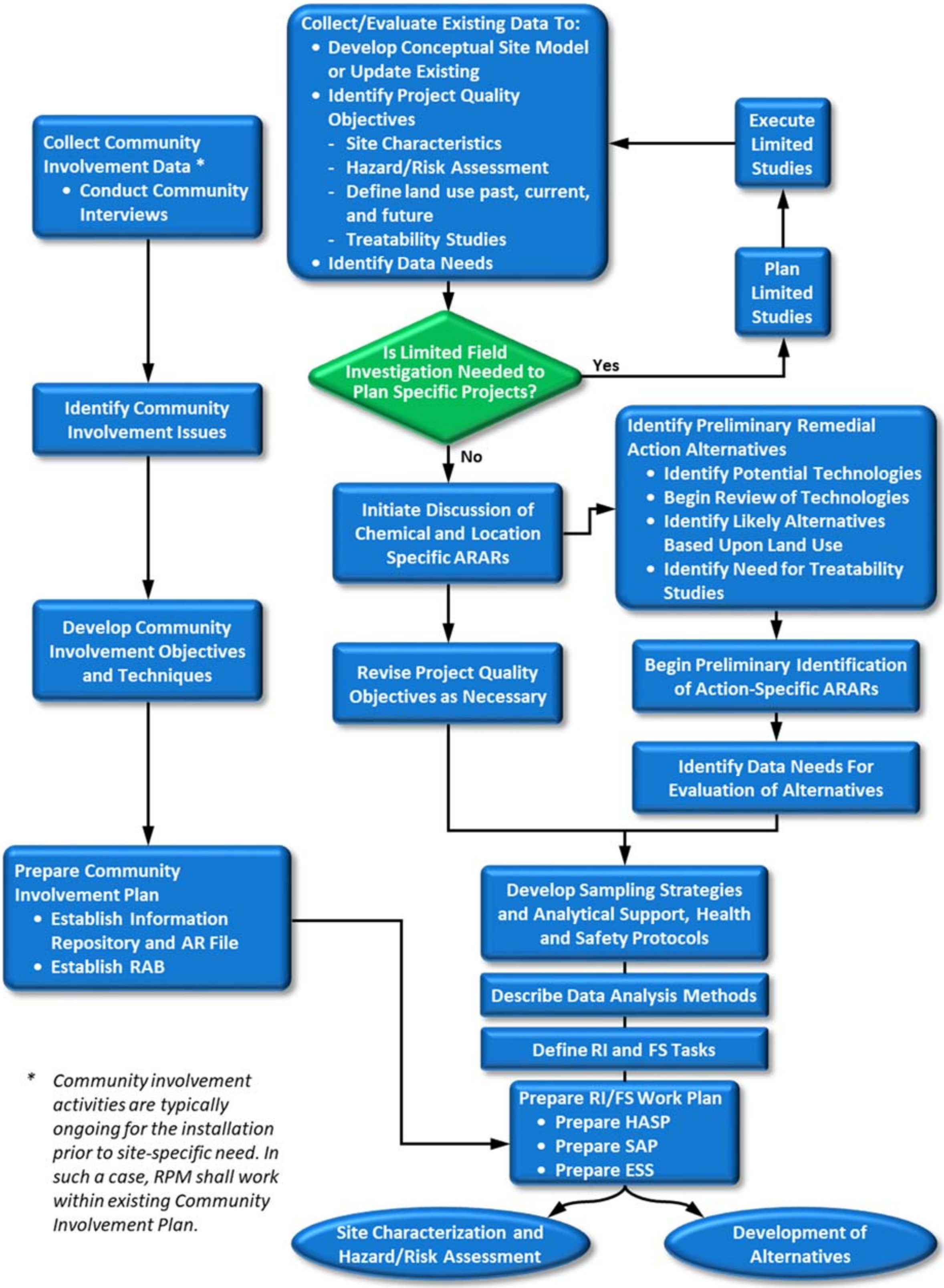

Figure 3-1. RI/FS Scoping Process

areas which are inaccessible for the RI/FS. The project team must decide what, if any, areas are considered inaccessible. In some cases, areas may be considered inaccessible due to unacceptable risk to workers; worker safety is the highest priority at a site. The following are examples of criteria that may be used by the project team in identifying inaccessible areas:

- Sites contaminated with improved conventional munitions (e.g., submunitions);
- Steep slopes (must be defined, but 30° has been accepted);
- Water (prevents positive fuze identification);
- Under pavements, buildings, or any fixed objects;
- Encased in biological growth, e.g., tree roots, coral, etc. (prevents proper detection).

Project teams should evaluate and collect data on other limitations that may impact the analysis of alternatives in the RI/FS. This can include evaluating what agencies have the authority and are willing to enforce LUCs or underwater use controls. Also, an evaluation of what the base/property owners or future owners will accept also should be performed.

Project teams should agree on the data elements to be collected in the scoping sessions. RI/FS scoping sessions should also include a discussion of items that are administrative in nature, such as the project plan review/approval process and budget availability, sequencing, and schedule requirements. Scoping sessions should include a discussion of these administrative items to ensure that the expectations of the stakeholders and project team are aligned.

3.1.1 RI/FS Definable Features of Work

Definable features of work (DFW) are tasks that are separate and distinct from other tasks and have control requirements unique to that task. The following is a list of major DFW that should be considered when scoping a RI/FS at a MRS:

- Site survey/grid layout;
- Vegetation removal;
- Anomaly avoidance;
- Surface/subsurface removal;
- Instrument verification (for underwater sites;)
- Geophysical system verification (GSV);
- Digital geophysical mapping (AGC, DGM);
- Anomaly reacquisition and intrusive investigation; and
- MEC/MPPEH management.

The purpose and typical tasks associated with several of these key DFW are summarized in Table 3-1.

3.1.2 Managing Terrestrial Sites

In some cases, small sites may warrant 100% geophysical survey, as opposed to spaced transects. Completion of 100% geophysical survey removes uncertainty and the possible need for

Table 3-1. Summary of Key Definable Features of Work

DFW	PURPOSE	TASKS
Site survey and grid layout	Install survey control so that the DGM data are correctly geo-referenced, the reacquisition coordinates are correctly geo-referenced, and so that survey instruments (GPS) can be QC-tested to verify accuracy to within project metrics. Verify that the stated location for the MRS is, in fact, the correct location. Install grids.	• Install survey control • Perform location surveys and mapping • Install grid corner points
Vegetation removal	Clear vegetation for safe and effective implementation of follow-on munitions response processes. Inadequate preparation of the MRS may make the implementation of follow-on processes less effective and possibly more hazardous due to poor surface visibility.	• Mow grass and mulch • Trim limbs and remove trees • Burn (controlled) • Dispose of logs, stumps, and mulch • Document results
Anomaly avoidance	To better define footprint boundary, refine follow-on investigation techniques and areas and/or safely guide other field crews	• Divide work area into units with UXO techs walking search lanes • Avoid metal debris and UXO/DMM • Document results
Surface removal	May vary based on the specific objective of the munitions response project. Surface removal may be performed to detect, identify, and remove a majority of the UXO, DMM, and metal debris from the surface of the production area to support follow-on processes (e.g., DGM) which result in the final UXO/DMM removal. Or, surface removal processes may be used as the final remedial action, which results in a site that is prepared for its future land use.	• Divide work area into units with UXO techs walking search lanes • Remove metal debris and UXO/DMM • Document results
Subsurface removal	Remove subsurface metallic objects that are detected during analog mag and flag operations, or, to investigate target anomalies derived from DGM.	• Excavate using hand tools or earth moving machinery to remove the overburden • Positively identify the source of the anomaly as MPPEH (MEC/MPPEH), or as non-munitions debris (e.g., construction debris, geologic, no-find, etc.) • Document the results
GSV	Verify on-site capabilities of the geophysical system(s).	• Design • Construction • Implementation • Reporting
DGM	Detect and locate metallic objects for investigation.	• Collect and record geophysical sensor and position data • Process, analyze, and interpret data to identify potential UXO/DMM • Create "dig list" for anomaly reacquisition and investigation • Document results
AGC	Detect, classify, and locate targets of interest (TOIs) for investigation.	• Collect and record geophysical sensor and position data • Process, analyze, and interpret data to identify TOIs • Create "dig list" for TOI reacquisition and investigation • Document results
Geophysical survey - analog	Detect and locate metallic objects through the use of geophysical sensors operated in "analog mode" (i.e., digital data are not logged and processed to generate target anomaly lists and maps).	• Divide work area into search lanes • Survey each lane using geophysical sensor relying on the analog signal (e.g., tone) to signal an anomaly • Mark each anomaly using a pin flag, etc. • Excavate anomaly locations
Anomaly reacquisition and investigation	Ensure all anomalies are unambiguously explained and managed post-excavation per project requirements	• Reacquisition (confirm presence/absence of anomaly) • Excavation • Post-excavation activities (inspect and manage MEC/MPPEH)
MEC/MPPEH Management	Control of MEC and MPPEH from discovery through disposal; identification of MEC requiring BIP; proper storage of MEC/ material documented as an explosive hazard (MDEH); proper siting of explosives storage magazines; proper inspection of MPPEH; proper disposal procedures for MEC and MDEH; conduct post-detonation inspection and reclamation.	• Positive identification of MEC • Assessment and documentation of MPPEH as either material documented as safe (MDAS) or MDEH • Proper disposal of MEC and MDEH • Demilitarization and recycling of MDAS

supplemental characterization. This approach is typically best suited for smaller areas (e.g., less than 20 acres in size). In addition, it may be appropriate to consider eliminating all encountered hazards/risks during the RI. This will save on contractor mobilization/demobilization costs and result in a cleaner site that can be considered for NFA/LUCs depending upon the results of the investigation.

It is important to fully understand the site's environment, including the geology, hydrogeology, lawfully protected biota and habitat (e.g., threatened or endangered species or special species), the types of MEC potentially present, terrain and vegetation (to determine whether vegetation removal is required), and in the case of forested areas, to determine which geophysical sensors may or may not be appropriate and whether a global positioning system (GPS) will work for data positioning. All of these site characteristics influence which DGM sensors are appropriate, the type of sensor platform that may be used (influences productivity and cost), data positioning, safety considerations, and intrusive work procedures.

3.1.3 Managing Underwater Sites

Managing underwater sites under the MRP presents a unique set of challenges not encountered at terrestrial sites, including unique environmental conditions (e.g., mobility of items, etc.), operational difficulties (e.g., use of divers, specialized equipment, etc.), and the need to evaluate environmental impacts with respect to MEC treatment (e.g., transmittal of shock wave, etc.) at underwater sites.

Before the RI can begin, it is important to fully understand the site's environment, including the type of environment (e.g., ocean, bay, river, lake, island), hydrography (e.g., depth, currents, wave action, tides, water clarity, turbulence), local weather, bottoms (e.g., soft, hard, sediments), habitat (e.g., sea grass beds, coral reefs, open bottom, swamps, marshes), and inhabiting biota (especially threatened and endangered species). These environmental conditions can affect MEC detection and identification at underwater sites. For example, bottom topography can create obstructions and navigation hazards or poor visibility in water, and the dynamics of the near shore environment (wind, waves, and currents) can interfere with anomaly detection and identification. Below are some resources that can be used to identify information related to these environmental conditions:

- Base Environmental staff (natural resources personnel, etc.)
- Wind and fog: National Climatic Data Center http://www7.ncdc.noaa.gov/CDO/CDOMarineSelect.jsp
- Waves: National Buoy Data Center
- Currents: Scripps Institute of Oceanography http://www.hfnet.ucsd.edu/thredds
- Threatened/endangered species: NOAA Office of Protected Resources, Endangered Species Act (ESA)
- Essential fish habitat: NOAA Habitat Conservation

- Marine mammal protection: NOAA Office of Protected Resources, Marine Mammal Protection Act (MMPA); U.S. Fish and Wildlife Service (USFWS)

There are challenges in conducting RI activities at underwater sites not only related to the environmental conditions present, but also due to operational difficulties in these environments. Similar to terrestrial sites, detection of small items may not be possible with the currently available survey technologies, and commercially available geophysical sensors for use in underwater environments are not able to distinguish metallic clutter from MEC. This results in a high cost to investigate and identify non-hazardous items. Operational challenges affecting MEC detection and identification specifically at underwater sites include:

- Poor control of sensor to bottom standoff distance;
- Dive operations slower than terrestrial operations;
- Limited detection sensor capability;
- Determining the status of any fuzing and hazard associated with the detected MEC (i.e., DMM = unfuzed, unarmed and UXO = fuzed, armed); and
- Bottom clutter of natural and manmade features.

As with terrestrial sites, underwater sites should be managed according to size. In some cases, small sites may warrant 100% investigation, as opposed to spaced transects. This investigation approach removes uncertainty and the possible need for supplemental characterization, but it must consider any impact to endangered species. A removal action may be warranted for small sites. During the RI, all encountered hazards/risks should be eliminated, if possible, to save on contractor mobilization/demobilization costs. Implementation of this approach at a small site will result in a cleaner site following completion of the RI activities. Depending on site specific conditions a decision to manage underwater hazards in place may also be acceptable.

In addition to the size of the site, the depth of an underwater site, and the wave dynamics affecting the mobility and exposure of MEC, should be considered in developing the RI approach. In shallow depths, hand-held detectors or small remotely operated vehicles (ROVs) with cameras/sonar devices may be suitable. At intermediate depths, small boats towing sensor arrays may be more appropriate, and at depths to 120 ft, autonomous underwater vehicles (AUV) and ROVs with on-board or towed sensor arrays are most effective. Usually the most effective characterization of an underwater site will be with a combination of sensors. Figure 3-2 provides an example of some technology selection criteria. As technologies for investigating underwater sites rapidly advance project teams should assess available technologies at the project planning stage.

3.1.4 Quality Control/Quality Assurance

DON's goal is to ensure that an auditable, objective record is maintained for all aspects of DON munitions response actions. To meet this objective, OPNAVINST 8020.15 (Series)/MCO 8020.10

(Series) *Explosives Safety Review, Oversight, and Verification of Munitions Responses* [3][4] requires that NAVFAC develop QA/QC procedures for all munitions response actions. Development of appropriate QA/QC procedures ensures the integrity of the data gathered through appropriate reviews and inspections. An audit record documenting the completion of activities and the associated QA/QC procedures should be maintained as part of the QA/QC program. The munitions response QA program only addresses the explosive safety hazard posed by MEC. The QA/QC procedures associated with the risk presented by MC contamination is addressed through the HHRA and ERA process.

QC is a product-oriented technique or activity designed to evaluate a completed task or product. QC activities are focused on finding defects in specific deliverables. The quality is determined by comparing a completed product against the requirements which were developed for that product. There are three phases of QC inspection (i.e., preparatory, initial, and follow-up) that are performed for each DFW. Routine QC activities include inspections to ensure that field work is conducted in accordance with work plans and standard operating procedures (SOP), and checking field equipment with the QC criteria and QAPP. QC activities are performed by the production contractor. Inspection points, frequency and inspection metrics are determined by the Project Team and are documented in the QAPP.

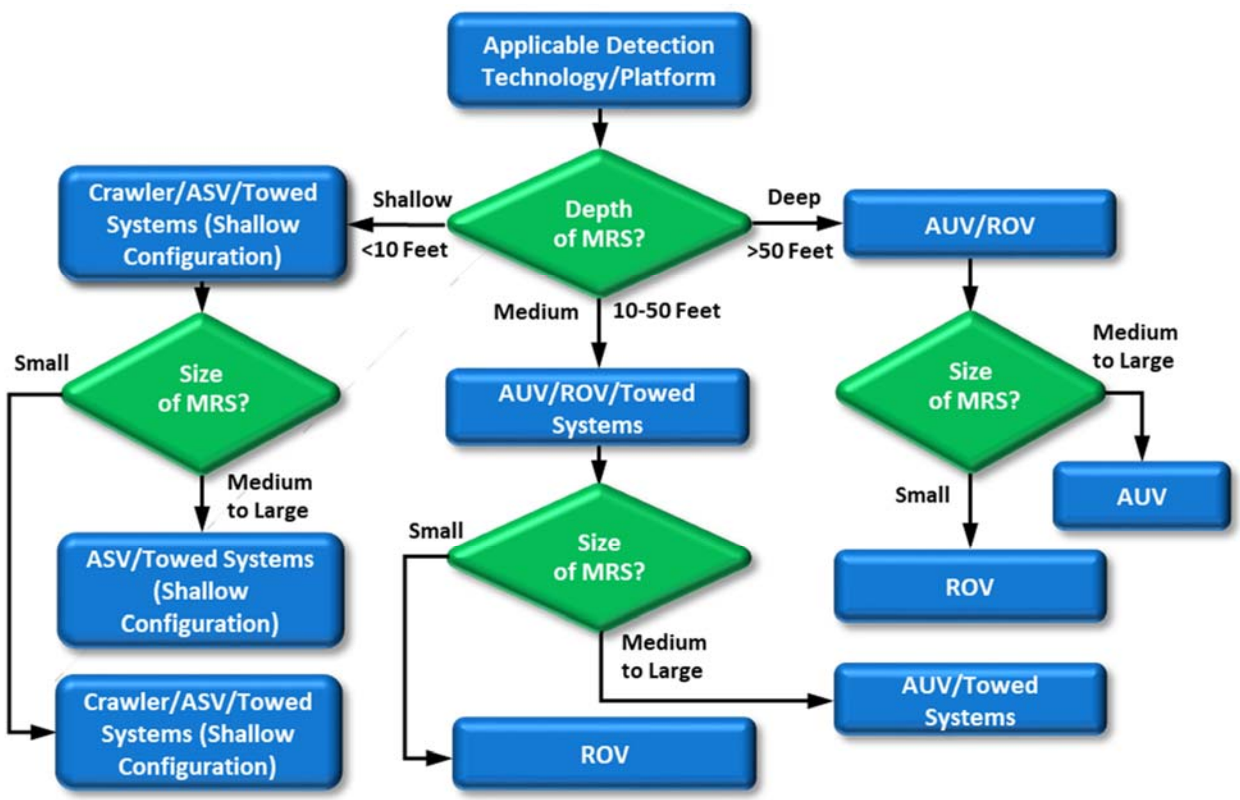

Figure 3-2. Example Underwater Technology Selection Criteria

The three-phase inspection process is a commonly used to implement QC on a project. Using the three-phase inspection process, inspections are done during various phases of work or what are referred to as the DFW. The Preparatory Phase inspections are typically carried out well in advance of initiating the task and includes reviewing the requirements for the task, assessing the current site status/situation, and reviewing the findings with work personnel and client. The Initial Phase inspections are conducted just prior to starting a task and includes checking that all requirements are in place, verifying that the site/task materials are prepared, and inspecting the initial work to make sure work can continue. The Follow-up Phase inspections are conducted throughout the task and includes monitoring tasks on a daily or reoccurring basis and that requirements are being met and verify that tasks are being performed correctly until completed.

QA is a process-oriented technique that ensures all processes are defined and appropriate. QA reviews should focus on the process elements of a project, including a review of whether project requirements are defined at the proper level of detail. This includes a review of data quality elements defined in the statements of work (SOWs), work plans, QAPPs (including PQOs), QCPs, ESSs, and SOPs, as well as requirements ensuring that qualified personnel, and proper geophysical and positioning equipment are used during the project. A review process is currently being put in place through the NIRIS database for documents generated for a MR site. It is envisioned that Echelon III commands (LANT, PAC, EXWC) will provide a review of MR site documents that can be tracked in NIRIS.

NOSSAINST 8020.15 (Series)/MCO 8020.10 requires a third-party, independent QA be performed by either a UXO contractor other than the RI contractor, FEC-qualified UXO staff member, or NSWC IHEODTD. Items for the RPM to consider when scoping independent QA activities include the frequency of audits and inspections needed (daily or intermittent), as well as the use of the MRS Self-Assessment Checklist (NOSSAINST 8020.15 (Series)/MCO 8020.10, Enclosure (4)) to evaluate the UXO contractor compliance with applicable environmental, safety, and occupational health requirements related to the management of munitions and MEC/MPPEH. Section 3.1.5 provides information on the example QA SOW that is available to assist RPMs in developing the QA scope.

In addition, RPMs and contractors can use the NAVFAC Quality Assessment Spreadsheet questions set to help develop content for the Quality Assessment Surveillance Plan (QASP), in addition to the Self-Assessment Checklist mentioned previously. The QASP will direct the QA regarding frequency of testing and activities evaluated. The following are examples of QA questions that may be asked when assessing RI/FS activities:

- In the QAPP are the appropriate personnel identified in WS #37 for performing the usability assessment?
- In the AGC QAPP do the DQOs specify that advanced classification will be used, that if the target is classified as a TOI it will be removed but if classified as non-TOI it will be left in place without investigation?

- During performance of surface removal, if technology-aided, were function checks of the metal detectors performed at the intervals required and the results documented as required in the approved plans?
- During AGC or standard DGM activities, are QC seeds placed at varying depths and orientations up to the maximum PWS detection depth?

The NAVFAC Quality Assessment Spreadsheet is available on MR Workgroup Reference DVD and NAVFAC portal.

3.1.5 RI/FS Resources

The MR Workgroup maintains a reference DVD that includes guidance documents, technical reference documents, templates, project documents as reference, and other MR related documents and information. The reference DVD and its contents are available from the MR Workgroup.

Several templates and cost estimating tools are available to assist RPMs in the MRP RI/FS process. There are five SOW templates available at NAVFAC Portal and on the Reference DVD, each developed by the Munitions Response Workgroup. Each of the SOW templates includes notes to the RPM that provide guidance on how to modify the contract language for their project. SOW templates relevant to the RI/FS include the RI/FS SOW, QA SOW, and small arms range RI/FS SOW. Each template includes the objectives and scope of the task order, document preparation requirements, and requirements for work elements relevant to the scope of work.

Examples of MEC QAPPs that have been developed, reviewed and implemented by the Navy are available as guidance for developing other site specific QAPPs. Often, the best QAPP to use as a starting point in developing a site specific QAPP is the one with similar work processes that has been developed and approved for a specific EPA region or state. A toolkit for a RI/FS MEC QAPP was recently produced by the Intergovernmental Data Quality Task Force (IDQTF) and is available on the MR Reference DVD and the Denix website. This toolkit pertains directly to the RI/FS phase and should be used as a starting point for developing a site specific RI/FS QAPP. An AGC QAPP template is also available from the IDQTF and is required to be used as a starting point if using AGC equipment, but it relates to the remedial action phase. RPMs should use the RI/FS QAPP toolkit for developing their site specific QAPP unless other factors indicate that another QAPP is a better starting point. These factors could include such things as an underwater MRS, a small MRS that is going to be 100% investigated, or a site that requires soil screening during the RI/FS. The MR Reference DVD has the IDQTF QAPPs and several other QAPPs that have been developed.

The Interstate Technology and Regulatory Council (ITRC has developed a number of reference and guidance documents and training courses that can assist RPMs and project teams during the RI/FS. Those documents are available at the ITRC's webpage. Some of these documents/training courses are:

- Geophysical Classification for Munitions Response;

- Quality Considerations for Multiple Aspects of Munitions Response Sites; and
- Survey of Munitions Response Technologies.

Cost estimating for terrestrial RI/FS actions can be accomplished by using previously awarded contracts by modifying the quantities based on the site specific backup information. Remedial Action Cost Engineering Requirements (RACER) is a cost estimating tool that is acceptable and can be used by RPMs and project teams to determine the cost of future actions if suitable previously awarded contract information is not available. Additional resources for the RPM include an RI/FS cost estimating tool developed by the Munitions Response Workgroup for use at terrestrial sites, and the underwater RI/FS cost estimating tool. The tools were created in a user-friendly format within the Excel program and contain modifiable fields for customization to fit site specific requirements. Previously awarded contracts and RACER are the preferred cost estimating tools for terrestrial site cost estimates. Previously awarded contracts or the workgroup developed underwater RI/FS cost estimating tool are the preferred tools for underwater sites, since RACER does not estimate underwater costs. The workgroup developed tools are available from any member of the workgroup. Members can also help with the use and implementation of the tools and cost estimates in general. Table 3-2 summarizes the worksheets included in the underwater site RI/FS cost estimating tool.

When developing cost estimates using these tools, it is helpful to keep a few items in mind with respect to production rates. A production rate of 1 acre/day for land-based DGM is a reasonable assumption for a man-portable geophysics system. For a towed array geophysics system, a production rate of 10 acres/day for land-based geophysics is a reasonable assumption.

Table 3-2. Summary of Worksheets in the Underwater Site RI/FS Cost Estimating Tool

WORKSHEET	SUMMARY
Overview	Contains basic instructions on using template
Site Information	Enter project information; contains default values if certain information is currently unknown
Summary	Provides the cost estimate for each project task conducted during the RI/FS
Calculation Areas 1 - 3	Provides calculations used to determine project costs for each task
Cost Range	Provides a range of cost for each task based on the complexity of each site
Cost Backup	Provides line item cost estimates developed from various sources of pricing data
Definitions	Defines terms used in the template
References	Provides cost data source list

3.2 Systematic Planning and Project Quality Objectives

The ultimate success of the project depends on the quality of the environmental data collected. This quality depends significantly on the adequacy of the SAP and on its effective implementation. The UFP-QS supports the generation/collection of defensible data appropriate for its intended use, and the uniform planning and documentation of projects using quality system concepts.

The PQO process is a planning process that is part of the systematic planning process. Another example is the Triad approach. The PQO process and Triad approach are two EPA programs defining systematic planning. Other approaches also exist such as the USACE Technical Project Planning process. Through a systematic planning process, a team can develop the acceptance and performance criteria for the quality of the data collected and for the quality of the decision(s) to be made within the program.

Systematic planning is a process based on the widely-accepted "scientific method" and includes concepts such as objectivity of approach and acceptability of results. The process uses a common-sense approach to establish project requirements and level of effort according to the intended use of the results and the degree of confidence needed in the quality of the results. The systematic planning approach includes well-established management and scientific elements that result in a project's logical development, efficient use of resources, transparency of intent and direction, soundness of project conclusions, and proper documentation to allow determination of appropriate level of peer review [23]. This approach reduces costs and allows the intended use to drive the degree of documentation and effort required. The amount of detail is dependent on the need for making the decision. An example would be the difference between an investigation, where the goal is to define the site boundaries, and an RI, where the goal is to determine the nature and extent of MEC/MPPEH.

Table 3-3 presents the elements that make up the systematic planning process. The explanation of these elements is found in Appendix A of the UFP-QS document. Refer to Table 1 UFP-QAPP to see how the UFP-QS systematic planning process compares to the UFP-QAPP elements.

Table 3-3. Elements of Systematic Planning

ELEMENTS
Organization: Identification and involvement of the project manager, sponsoring organization and responsible official, project personnel, stakeholders, scientific experts, etc. (e.g., all customers and suppliers).
Project Goal: Description of the project goal, objectives, and study questions and issues.
Schedule: Identification of project schedule, resources (including budget), milestones, and any applicable requirements (e.g., regulatory requirements, contractual requirements).
Data Needs: Identification of the type of data needed and how the data will be used to support the project's objectives.
Criteria: Determination of the quantity of data needed and specification of performance criteria for measuring quality.
Data Collection: Description of how and where the data will be obtained (including existing data) and identification of any constraints on data collection.
QA: Specification of needed QA and QC activities to assess the quality performance criteria (e.g., QC samples for both field and laboratory audits, technical assessments, performance evaluations, etc.).
Analysis: Description of how the acquired data will be analyzed (either in the field or the laboratory), evaluated (i.e., QA review/verification/validation), and assessed against its intended use and the quality performance criteria.

Systematic planning is a team-based approach to planning that engages all stakeholders and promotes communication between all organizations involved. It is based on a holistic view of the entire project from the beginning to end. The usefulness of every action must be assessed in terms of how efficiently it moves the project toward its goal. Through a systematic planning process, a team can develop the performance criteria for the quality of new data collected (PQOs) and acceptance criteria to evaluate the adequacy of existing data as being acceptable to support the project's intended use.

Project requirements originate from the PQOs developed by the project team. PQOs are only a requirement if they are agreed to by the entire project team. The requirements are understood by all and are memorialized in the SAP/QAPP, e.g., PQOs for the PA are in the PA QAPP, PQOs for the investigation are in the investigation QAPP, etc. Note that these requirements are now referred to as PQOs instead of DQOs because they are for the entire project, not just the data.

3.2.1 <u>EPA Seven-Step Process</u>

EPA's PQO process consists of seven iterative steps (Figure 3-3). While Figure 3-3 shows the interaction of these steps in a sequential fashion, the iterative nature of the PQO process allows one or more of these steps to be revisited as more information on the problem is obtained.

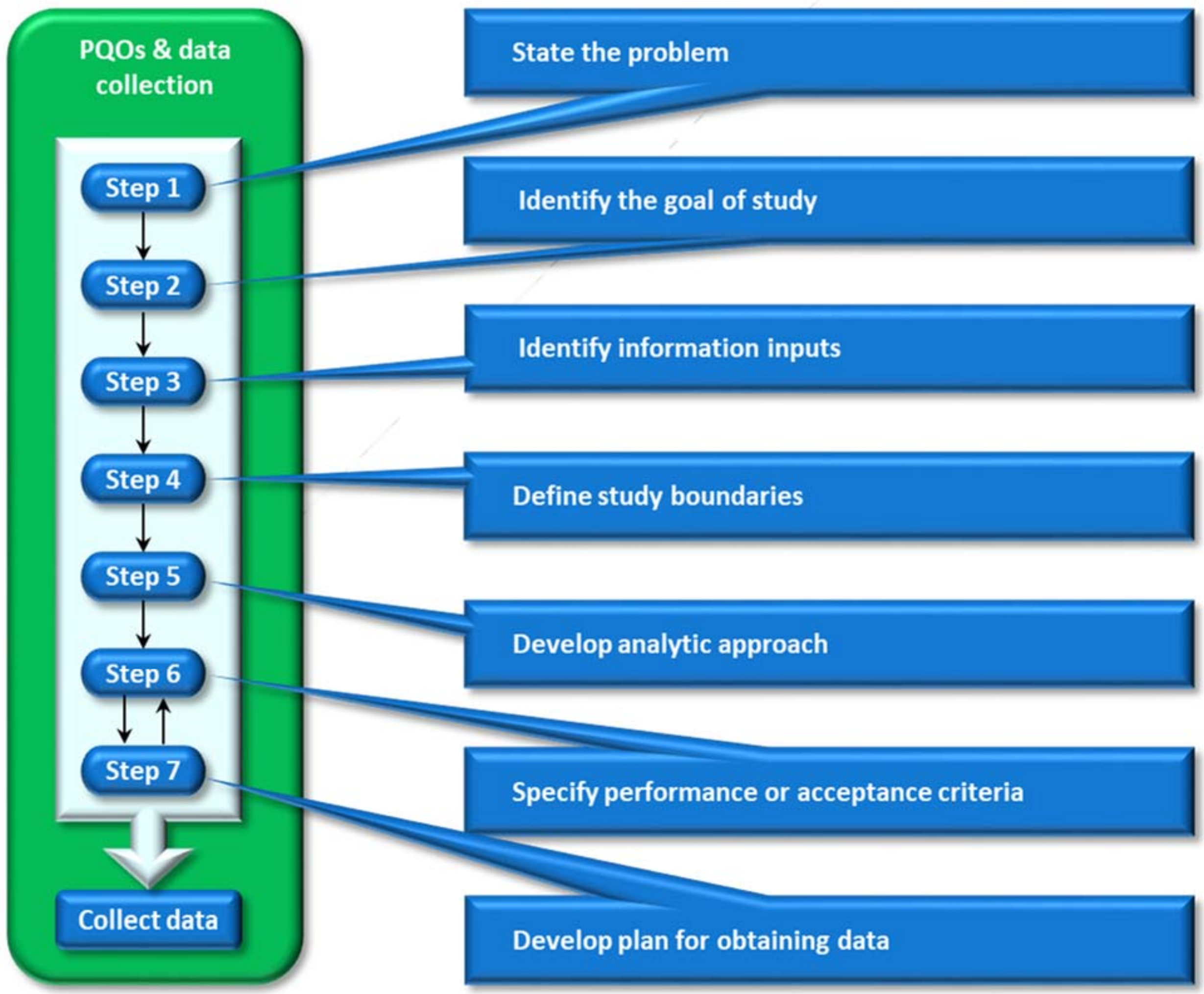

Figure 3-3. EPA's Seven-Step PQO Process

Each step defines criteria that will be used to establish the final data collection design. The first five steps are primarily focused on identifying qualitative criteria, such as:

- the nature of the problem that has initiated the study and a conceptual model of the environmental hazard to be investigated;
- the decisions or estimates that need to be made and the order of priority for resolving them;
- the type of data needed; and
- an analytic approach or decision rule that defines the logic for how the data will be used to draw conclusions from the study findings.

In general, the ultimate users of the data will be DoD and regulatory agency representatives with formally recognized roles in decision making (e.g., Navy RPM, EPA Project Manager, and State Environmental regulatory agency). Other stakeholders or technical experts may participate in advising these representatives (e.g., hazard [risk] assessors, tribal representatives, NOSSA, geophysical scientists, public, etc.), but the representatives in decision-making roles should be clearly identified.

The sixth step establishes the PQOs relative to the ultimate use of the data. The PQOs identify the requirements that the collected data will need to achieve in order to minimize the possibility of either making erroneous conclusions or failing to keep uncertainty in estimates to within acceptable levels. Performance criteria, together with the appropriate level of QA practices, will guide the design of new data collection efforts, while acceptance criteria will guide the design of procedures to acquire and evaluate existing data relative to the intended use.

For MEC projects, data will generally be used for determining or evaluating

- the need for additional investigation;
- if a remedial or removal action should be considered for the site or area within the site (or, alternatively, if NFA is necessary);
- remedial alternatives as part of a FS planning for a remedial action; or
- implementation of a selected remedy or removal action and ensuring that RAOs have been met.

Other possible uses of the data may include determining or refining boundaries, estimating MEC density, confirming absence, or presence of MEC, QA or QC, or confirming previous removal area(s). In any case, the uses of the data should be clearly documented and agreed to by the project team. If no clear use of a data element can be identified, the data should not be collected.

In the seventh step of the PQO process, a data collection design is developed to generate data meeting the quantitative and qualitative criteria specified at the end of Step 6. A data collection design specifies the type, number, location, and physical quantity of samples and data, as well as the QA and QC activities that will ensure that sampling design and measurement errors are managed sufficiently to meet the PQOs. The outputs of the PQO process are used to develop the QAPP (Section 3.3.1). Table 3-4 provides some sample PQOs. Also, the example MEC UFP-QAPP discussed in section 3.3 has an example of PQOs for a site and is available from the NAVFAC Portal.

The matrix for MEC projects can include terrestrial sites (including intertidal areas) with MEC on the surface and subsurface or underwater areas with MEC buried or proud to the bottom. The project team should identify the type of detection technology, sensor platform, data processing

Table 3-4. Sample PQOs

EPA's Seven-Step Process	Sample PQO
State the problem	Confirm the location of targets, establish boundaries, characterize MEC items, evaluate risk, and collect data for FS for areas requiring remedial actions
Identify the goals/principal study questions	What is desired future land use for all areas of the site? What is the nature and extent of the explosive hazard vertically and horizontally? What are appropriate investigation and cleanup criteria?
Identify information inputs to the principal study questions/CSM	For MEC: ▪ Additional surface data to determine horizontal extent ▪ Intrusive data to establish density and vertical extent ▪ Cleanup clearance requirements for potential land use
Define study boundaries	Horizontal and vertical boundary for both MEC and MC, considering 30º slope rule
Develop decision rules/data collection and analysis approach	For MEC: ▪ "Step-out" grids if MEC discovered at boundary of AOC ▪ Develop VSP inputs, e.g. If an area has an anomaly density ≥ critical density, it will be considered a target area ▪ NFA for a decision unit (DU) if no MEC/MPPEH or MC are found; site boundaries readjusted accordingly
Specify tolerable limits on decision error/MPCs	Completion of RI sampling IAW criteria defined in QAPP e.g. WS #12 Measurement Performance Criteria
Optimize design for obtaining data/project workflow	Selection of the most resource-effective sampling design that satisfies PQOs (see QAPP Worksheet #17); Develop DFWs that support project objectives (see QAPP Worksheet #14)

protocols, and field procedures to be used to identify these items (e.g., AGC, magnetometer or electromagnetic sensors, man portable or towed platforms, etc.). Guidance concerning available technologies for investigation of MEC sites may be obtained from the ITRC documents discussed in section 3.1.5 and the ACOE's EM 200-1-15. The SERDP and Environmental Security Technology Certification Program (ESTCP) websites also have information on classification technology and underwater technologies.

As described in section 3.1, project teams need to determine the specific data requirements for the project. Data required for the MEC HA to calculate Hazard Level Scores and ESS/AAR requirements should be considered, for example depth and type of MEC. Non-munitions item data that may be considered for collection include, but is not limited to pictures, location, identification, maps, transects traveled, percent of area covered, cultural problems encountered, foliage present during season, weight of debris removed, etc.

3.2.2 Conceptual Site Model

A conceptual site model (CSM) is a tool that describes a site and its environmental setting. The CSM establishes a working hypothesis of the nature and extent of contamination (DMM, UXO, and MC), including the types of contaminants (*sources*), routes of contaminant migration with focus on geologic and hydrologic models (*pathways*), and potential current and future receptors and exposure routes (*receptors*). A good CSM is used to guide the investigation at the site. The initial CSM is created during the PA/SI with historical information on range use and the results of preliminary investigations. The CSM continues to evolve and be revised as new data about the site are collected during the RI and future removal actions. Key pieces of initial data to be recorded in the CSM include, but are not limited to:

- The topography and vegetative cover of various land areas;
- The prevailing meteorological or weather systems of the area;
- Past munitions-related activities (e.g., munitions handling, weapons training, munitions disposal) and the potential releases that may be associated with these activities;
- Expected locations and the depth and extent of contamination (based on the MEC activities);
- Likely key contaminants of concern;
- Potential exposure pathways to human and ecological receptors (including threatened and endangered species);
- Terrestrial environmental factors such as frost line, erosion activity, and the GW and surface water flows that influence or have the potential to change pathways to receptors;
- Underwater factors such as recreational fishing, diving, swimming, and boating and underwater features (e.g. coral reefs, seagrass beds, waves, currents) that influence or have the potential to change pathways to receptors;
- Human factors that influence pathways to receptors, such as unauthorized transport of MEC;
- Location of cultural or archeological resources; and

- The current, future, and surrounding land uses.

The CSM can be presented using text, tables, figures, or maps (or combinations of these) to represent the vertical and horizontal aspects of the site. An example CSM for the Waikane Valley site is shown in Figure 3-4. Additional information on the CSM for MRS can be found in EPA's *Handbook on the Management of Munitions Response Actions* [20]. An example of a vertical CSM is shown in Figure 3-5.

3.3 RI/FS Planning Documents

The RI/FS planning documents are prepared to document the RI/FS approach and goals agreed upon by the project team during the RI/FS scoping activities. Each of the relevant DFW should be included in the RI/FS planning documents to document how the investigation will be completed to achieve the project goals. Key planning documents for the RI/FS Work Plan include the SAP and the ESS. Other documents are required as well (e.g. Health and Safety Plan, etc.)

When removal or RIs are conducted under CERCLA and the NCP, SAPs are prepared to ensure that the data obtained are of the quantity and quality necessary to support the decisions made. These SAPs will generally consist of two parts: (1) a field sampling plan that describes the number, type, and location of samples and the types of analyses, and (2) the QAPP, which describes the current organization, functional activities, PQOs, and actions necessary to ensure that the data are adequate for use in selecting a remedy. Section 3.2 provides additional information on systematic planning and development of the PQOs. The following subsections provide information regarding preparation of these key elements of the RI/FS Work Plan, the UFP-QAPP and ESS.

3.3.1 UFP-QAPP

Preparation of a properly documented work plan is required to historically reconstruct what activities were completed for the project. Preparation of the UFP-QAPP provides a project-specific "blueprint" for obtaining the type and quality of environmental data needed for a specific decision or use in the project. It documents how QA and QC are applied to ensure that the results obtained will satisfy the stated performance objectives for the project. Additional information related to the UFP-QAPP guidance is provided in Section 2.1.3.

Two QAPPs are typically developed for each RI at an MRS — one to address MEC and a second to address MC. QAPPs are reviewed and approved by NAVFAC Atlantic and NAVFAC Pacific, respectively, as well as the regulators. Individual FECs or projects may have required review procedures in addition to NAVFAC Atlantic and Pacific reviews.

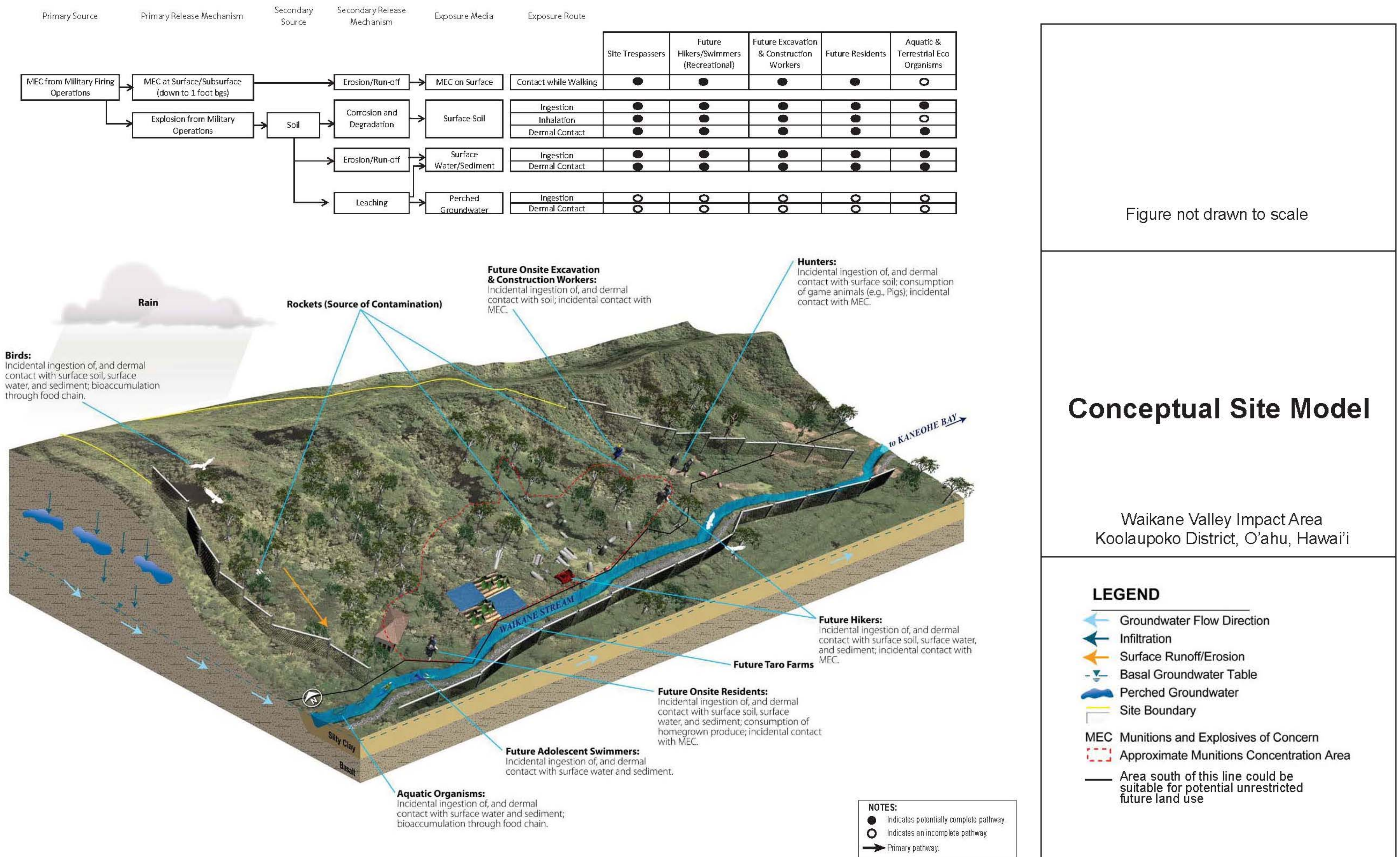

Figure 3-4. Example CSM, Waikane Valley

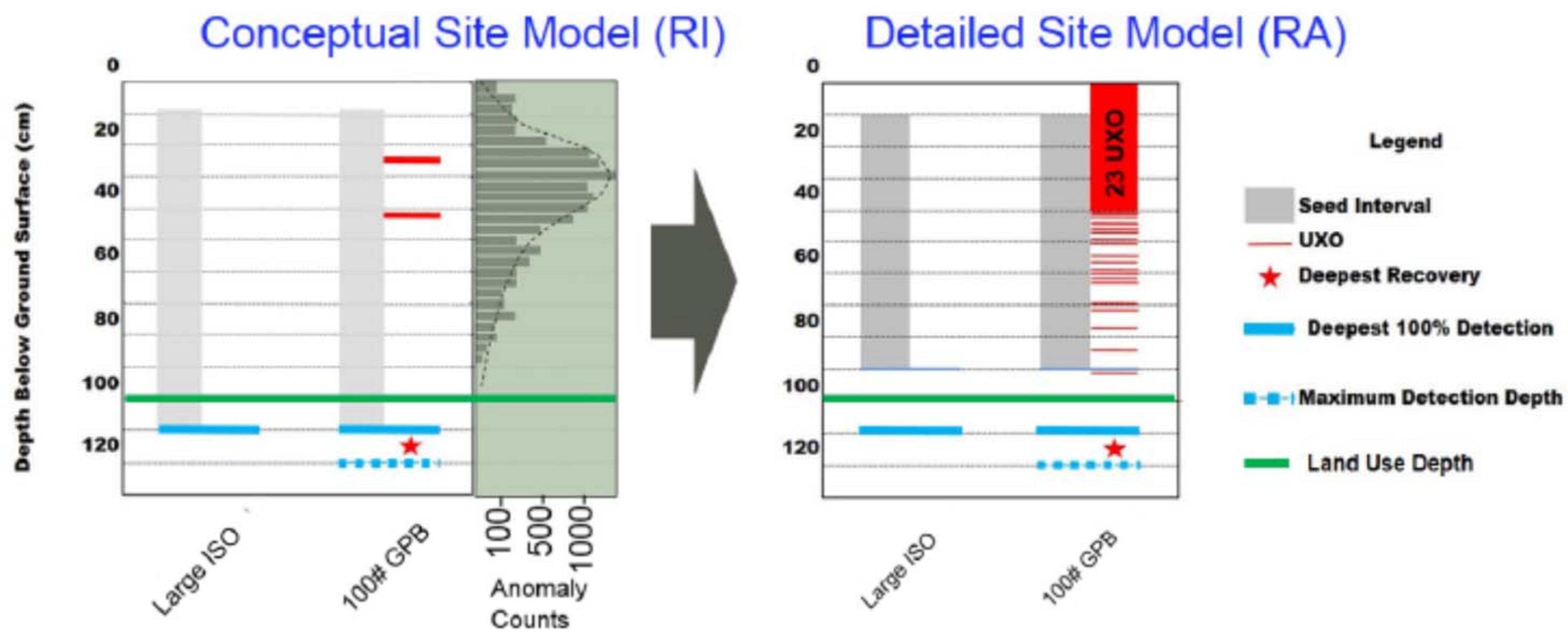

Figure 3-5. Example Vertical CSM

Example MEC UFP-QAPPs are available from MR Workgroup. The examples provide guidance to RPMs for some of the specific issues related to completing a MEC UFP-QAPP for work at NAVFAC MRSs. Example QAPPs that may have been reviewed by the same state or EPA region may be available. Additionally, QAPPs with similar work approach (e.g., DGM vs analog) may also be available. Previously reviewed and approved QAPPs and QAPPs with similar work approaches can provide the project RPM with a starting point that may result in decreasing review times and identifying specific reviewer concerns. For MEC RI/FS QAPPs, the Munitions Response QAPP Toolkit Module 1: RI/FS, December 2018 [24] is normally the best example to start development of the site specific MEC QAPP for RI/FS work.

Note that the UFP-QAPP workbook was revised by EPA in March 2012. The original workbook included 37 worksheets for preparation of the QAPP following the systematic planning process. The revised workbook consolidates several of the original worksheets and now contains a total of 27 worksheets.

RPMs can obtain example MEC QAPPs from their FEC MR work group representative, any other work group representative, or from NAVFAC Atlantic/Pacific QAPP reviewers. A list of potential SOPs for terrestrial and underwater MRSs is provided in Table 3-5. The example documents are provided so that the level of detail that was developed in each document can be understood.

- SAP Former NWS Seal Beach Concord Detachment
- SOP 1 Vegetation Removal
- SOP 2 Site Preparation
- SOP 3 RTK Differential Global Positioning System (DGPS) Operations
- SOP 4 DGM Operations
- SOP 5 DGM Data Processing
- SOP 6 Target Reacquisition
- SOP 7 Intrusive Investigation
- SOP 8 Intrusive Investigation Using Heavy Equipment
- SOP 9 MEC Management and Disposal
- SOP 10 MDAS Management and Disposal
- SOP 11 Ammunition Storage
- SOP 12 Contractor Significant Incident Report Documentation
- SOP 13 MEC Mechanical Screening Operations
- SOP 14 Excavation and Trenching

When preparing the UFP-QAPP, the worksheets generally cannot be filled out in order. Several worksheets are self-explanatory, including project identifying information, project organizational chart, personnel responsibilities, etc. Other worksheets cannot be completed, or can only be partially completed, until the relevant information is developed during the RI/FS scoping sessions and the systematic planning process. Note that the discussion below includes the current worksheet titles for the March 2012 revised UFP-QAPP workbook.

Table 3-5. Example Summary of MEC SOPs

TERRESTRIAL	UNDERWATER
Grid Layout	IVS Installation and Blind Seeding
Vegetation Removal	ROV Geophysical, Sonar, Video Survey and Data Collection
Anomaly Avoidance	Towed Geophysical and/or Sonar Survey and Data Collection
Surface Removal	Data Processing and Interpretation
IVS Installation and Blind Seeding	Diving Operations
Geophysical Survey and Data Collection	Diving Support Craft Operations
Data Processing and Interpretation	Target Reacquisition and Recovery
Target Reacquisition	MEC Treatment Operations
Intrusive Investigation	MPPEH Management
MEC Treatment Operations	Dredging Operations
MPPEH Management	Dredge Spoils Management
Magazine Inspections and Security	
All-Terrain Vehicle (ATV) and Utility Vehicle Operations	

The importance of maintaining documentation of scoping meetings and the agreements and decisions that are arrived at during these meetings cannot be overemphasized. This applies to all projects requiring a systematic planning process. The number of scoping meetings and the formality of documentation required to support them will vary with the composition of project teams and the complexity of the project. In some cases, project plans may require multiple meetings of the project team over the course of an extended period of time (months). In other cases, a single teleconference may be all that is necessary to resolve PQOs and agreements necessary to support these objectives. All scoping sessions should be documented using Worksheet #9 of the UFP-QAPP.

The items agreed upon and decisions made during the scoping sessions are documented on several other UFP-QAPP worksheets. Worksheets #10 and #11 document the CSM and PQOs developed during these sessions. These worksheets discuss what will be accomplished in broad terms, while Worksheet #14 identifies the major tasks, DFW and schedule for the project, and Worksheet #17 discusses how each of these tasks will be completed as well as the rationale for selecting the investigative methods in order to meet the project objectives. Worksheet #17 closely resembles the narrative that was provided in the previously used technical memorandum format for work plans.

It is assumed that the project team has developed a CSM for the site that provides background information on site characteristics (Section 3.2.2) as well as a description of the sources of MEC, pathways that could result in receptor exposure to explosive hazards, and the receptors and the activities that currently occur on the site or could occur in the future. It is important that this CSM be agreed to by the project team, and that the discussions leading to agreement on the CSM are well documented. The CSM will be the foundation for the project team's development of the problem definition statement and activities required to achieve the project goals.

Data collection during the RI at MRS is governed by the methods and SOPs identified and documented in the QAPP. Of the QAPP worksheets, the ones listed below contain the bulk of the operational and QC information:

- Worksheet #10 CSM and Worksheet #11 Project DQOs. Together, these worksheets describe the EPA Seven-Step DQO process and provide the problem statement and RAOs (Worksheet #10) and PQOs and systematic planning process statements (Worksheet #11);
- Worksheet #12: Measurement Performance Criteria. Worksheet 12 describes the measurement performance criteria for the characterization of MRS. Measurement Performance Criteria are the minimum performance specifications that the RI must meet to ensure collected data will satisfy the DQOs documented in Steps 1-5 on Worksheet #11. They are the criteria against which the intermediate and final data usability assessment (DUA) will be conducted as documented on Worksheet #37. The DUA must evaluate and document the data quality and decision-making impacts of any failures to meet these criteria (See Worksheet #37. Table 3-6 provides example measurement performance criteria.
- Worksheets #14: Project Tasks and Schedule. Describes the DFW for the project with all of the supporting subtasks for each DFW and schedule of activities;
- Worksheet #17: Sampling Design and Project Workflow. Documents and justifies the design for the RI. It documents Step 7 of the PQO process.
- Worksheet #22: Equipment Testing, Inspection, and QC. Documents the procedures for performing testing, inspections and QC for all field data collection activities. Some examples would be verifying correct assembly of equipment, positioning accuracy, and the GSV.
- Worksheet #29: Data Management, Project Documents and Records. Describes the procedures for controlling documents, records, and databases. It ensures data completeness, integrity, traceability, and ease of retrieval.

In most cases, unforeseen circumstances will be encountered during the investigation or remediation of a site. The QAPP should recognize the possibility of such unforeseen circumstances and, to the extent possible, provide a means of dealing with them that minimizes delays and cost impacts. As an example, previously unknown areas of significant metallic clutter unrelated to MEC incidence may be encountered at a site.

Conducting an intrusive investigation in such an area may not provide meaningful data to support decision making. In such a case, the QAPP should allow flexibility to obtain sufficient data to confirm the metallic debris is not MEC related without requiring intrusive investigation of 100% of the anomalies that may be identified in the debris area. Figure 3-6 shows an example decision tree for a terrestrial MRS that demonstrates this concept. Underwater sites should also develop decision trees prior to the collection of data.

Table 3-6. Some Example Measurement Performance Criteria

Measurement	Data Quality Indicator	Specification	Activity Used to Assess Performance
Detection threshold	Sensitivity	5 x the Root Mean Square (RMS) Noise for both transects and grids.	1) Review of sampling design 2) Initial verification at IVS 3) Background analysis prior to VSP Analysis
Positional data	Accuracy	Positional error will not exceed $\pm$0.1m for the full coverage/mini grids.	1) Review of sampling design 2) Initial verification at IVS.
QC seeding (AGC and DGM)	Accuracy/Completeness	High density characterization grids 1 seed/system/day.	Lead agency verifies all QC seed failures are explained and corrective action implemented.
QA seeding (Analog)	Sensitivity/Completeness	High density characterization grids 5-6 seeds/person/day. Resurvey of grid until all seeds are located	Lead agency oversight
Anomaly Classification (AGC)	Accuracy	100% of predicted non-TOI that are intrusively investigated are confirmed to be non-TOI	Visual Inspection of recovered items from classification validation

Upon completion of the field effort, it is appropriate to review data gathered to ensure the data package to be used to support a decision meets previously agreed upon standards for quantity and quality of data and that any deviations from these standards are evaluated to assess the impact these deviations may have on the decisions to be made by the project team. Some of the key worksheets that document the procedures and requirements for the usability assessment include Worksheets #34, #35, and #37.

- Worksheet #34: Data Verification, Validation, and Usability Inputs. Describes the three-phase inspection process the contractor will use to implement QC on the project. The three-phase inspection process is described in Section 3.1.4. Worksheet#34 lists the requirements/specifications (e.g. contracts, SOPs, planning documents) and inputs that will be used during data verification, data validation, and data usability assessments. Inputs include all field records (both hard-copy and electronic) and interim and final reports.

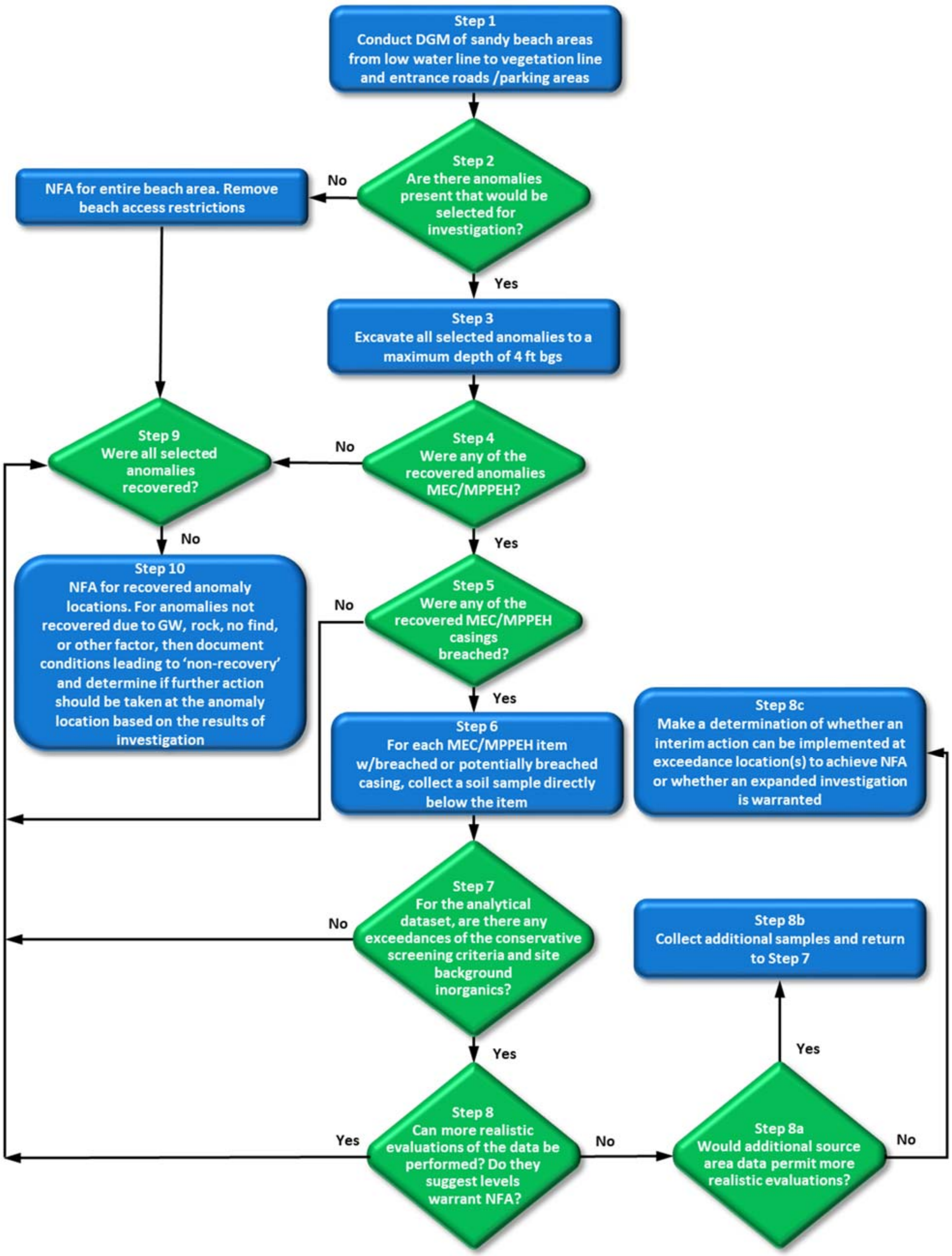

Figure 3-6. Example Terrestrial Decision Tree

- Worksheet #35: Data Verification and Validation Procedures. Lists DFW; documents frequency of inspection for each DFW; identifies supporting documentation (e.g., SOPs or other requirements) and describes of the validation process; identifies personnel responsible for validation. RPMs should use the DFW to identify the elements for validation. Data verification is a completeness check to confirm that all required activities were conducted, all specified records are present, and the contents of the records are complete. Data validation is the evaluation of conformance to stated requirements.
- Worksheet #37: Data Usability Assessment. Worksheet #37 summarizes the usability assessment process; describes evaluative procedures to assess measurement error; identifies responsible personnel; and describes the documentation of the usability process. The Data Usability Assessment involves a qualitative and quantitative evaluation of the data to determine if the project data are of the right type, quality, and quantity to support the measure performance criteria and PQOs specific to the investigation. It involves a retrospective review of the systematic planning process to evaluate whether underlying assumptions are supported, sources of uncertainty have been managed appropriately, data are representative of the population of interest, and the results can be used as intended with an acceptable level of confidence.

Note that several UFP-QAPP worksheets do not apply to MEC QAPP (Table 3-7). For completeness, all worksheets that do not apply should be retained in the QAPP and clearly labeled DOES NOT APPLY.

Table 3-7. Summary of UFP-QAPP Worksheets that Do Not Apply to MEC QAPPs

WORKSHEET #	TITLE
15	Reference Limits and Evaluation Table
18	Sampling Locations and Methods
19&30	Sample Containers, Preservation, and Hold Times
20	Field QC
21	Field SOPs
23	Analytical SOPs
24	Analytical Instrument Calibration
25	Analytical Instrument & Equipment Maintenance, Testing and Inspection
26&27	Sample Handling, Custody, and Disposal
28	Analytical QC and Corrective Action

3.3.2 ESS

Instructions for completing the ESS can be found in NOSSAINST 8020.15 (Series)/MCO 8020.10 Enclosure (3), "Guide for Preparing an Explosives Safety Submission" [3][4], and an example ESS is available on the MR Reference DVD. NOSSA has other example ESSs that may be the most appropriate to use as a starting point when developing the ESS. These may have similar site characteristics and work approaches that can be used to expedite the development and review process. MR workgroup members or NOSSA should be consulted to determine if another example ESS exists. Each munitions response operational category (i.e., MRS investigation/characterization, NFA determination, TCRA, on-site construction support, and execution of selected response) requires a unique set of information in the ESS. Enclosure (3) provides a table that identifies what information must be included and what information isn't required in ESS for each operational category.

Munitions response activities have the potential for either an intentional or unintentional detonation (due to mechanized or manual MEC operations). The ESS will identify explosives safety quantity-distance (ESQD) arcs and exclusion zones (EZs) to provide protection from two types of hazards resulting from an intentional or unintentional detonation: blast overpressure and fragmentation.

The ESS will identify the ESQD arcs and EZs based on project specific information, including the munition with greatest fragmentation distance (MGFD) and blast overpressure as determined by the types of MEC/MPPEH present.

The MGFD(s) are based on research or other characterization of the MRS, and is selected from among the MEC and/or MPPEH known to be present which have the greatest fragmentation distance. In developing the EZ, there are two fragmentation distances to be considered: maximum and hazardous. If one known munition item has a larger hazardous fragment distance, while another munition item has a larger maximum fragment distance, both must be identified as primary MGFDs (Primary-1 and Primary-2). This (these) will be the primary MGFD(s) for the site. A minimum of one contingency MGFD shall also be identified to reduce the potential for work stoppage. Selection of the contingency MGFD may be based on anecdotal evidence suggesting that a MEC and/or MPPEH item with a larger MFD may be present at the site. If the ESS covers multiple MRSs, then primary and contingency MGFD should be identified for each MRS.

For blast overpressure, protection is afforded by distance from the blast as calculated using K-values and the net explosive weight (NEW) from any source. Each K value corresponds to a certain pressure, (e.g., K24=2.3 pounds per square inch). As an example, the formula for determining blast overpressure separation distances for class/division 1.1 material is $D=KW^{1/3}$ where:

- D is the separation distance in feet
- K is a factor that varies depending on the risk assumed or permitted
- W is the NEW of the MGFD expressed in pounds of trinitrotoluene (TNT) equivalent

Based on this, Table 3-8 shows the levels of protection afforded essential and non-essential personnel against both blast overpressure and fragmentation during intentional and unintentional detonation for both mechanized and manual operations.

NOSSAINST 8020.15 (Series)/MCO 8020.10 Enclosure (3), "Guide for Preparing an Explosives Safety Submission" [3][4] provides a hierarchal list of sources of information for developing

MGFDs. Fragmentation Data Review Forms contain data on both the blast overpressure and fragmentation distances for some common munitions and are available by contacting NOSSA. Also, DDESB TP-16 has methodologies for calculating primary fragment characteristics.

The ESQD arcs and EZs are intended to protect essential and non-essential personnel. Essential personnel are those whose duties require them to remain within an ESQD arc to ensure the safe and efficient completion of the munitions response action. Examples of essential personnel include the contactor's UXO Safety Officer, Senior UXO Supervisor (SUXOS), and other work team members. Non-essential personnel are all others. In general, access to EZs is limited to personnel

Table 3-8. Example of ESQD Arcs and EZs Summary for ESS

PERSONNEL	INTENTIONAL DETONATION	UNINTENTIONAL DETONATION		
		MECHANIZED OPERATIONS		MANUAL OPERATIONS
		HIGH INPUT	LOW INPUT	
Essential	D=K328 or[(a)] MFD[(b)]	D=K24 + shield or barricade	D=K24 + shield or barricade	D=K40[(c)]
Non-essential	D=K328 or[(a)] MFD[(b)]	D=K328 or[(a)] MFD[(b)]	D=K40 or[(a)] HFD[(d)]	D=K40 or[(a)] HFD[(d)]

(a) Choose longest distance
(b) Maximum fragment distance
(c) Minimum separation distance (i.e., team separation distance)
(d) Hazardous fragment distance

essential to the operation being conducted. NOSSAINST 8020.15 (Series)/MCO 8020.10 [3][4] specifies the protocol to use to request and authorize entry to the EZ by non-essential personnel in the performance of their duties. Without this authorization, all hazardous work must stop if unauthorized personnel enter the EZ.

Normally the UXO contractor is tasked with drafting the ESS using Enclosure (3) of NOSSAINST 8020.15 (Series)/MCO 8020.10 [3][4]. Upon approval of the RPM, the UXO contractor may work with NOSSA directly and even submit preliminary drafts ahead of the formal submission. This approach increases communication and decreases misunderstandings and missteps. Formal submission of the ESS must include review and approval of the cognizant ESO and Facility Planner prior to review by NAVFAC, NOSSA and then DDESB. Anticipate a NAVFAC review time of 10 business days and NOSSA/MARCORSYSCOM review time of up to 1 month for each draft, and anticipate the same amount of time for DDESB to review and approve the final ESS. The ESS will be submitted via the WebESS or through the MAKE portal for Marine Corps ESSs.

ESS amendments are required when a change to an approved ESS increases explosives safety risks, identifies requirements for additional or increased explosives safety controls, or changes an ESQD arc. Amendments require NOSSA/MARCORSYSCOM and DDESB approval.

ESS corrections address changes to an approved ESS that do not increase explosives safety risks or exposures. Corrections are primarily administrative in nature and require NOSSA/MARCORSYSCOM approval only.

An amendment or correction to an approved ESS may not require the resubmission of the complete ESS package. If the number of amended or corrected pages is ten or less, only the modified pages need to be submitted. If the number of amended or corrected pages exceeds ten, the Navy project manager shall submit the entire amended or corrected ESS.

3.3.3 Dive Safety Plans

When conducting underwater RI activities, additional dive safety requirements must be considered. NAVFAC or the FEC District Diving Coordinator must review and approve all dive safety plans per Business Management System F-12.17.10 Contract Dive Safety Oversight Program. The following is a list of references for developing a dive safety plan:

- Occupational Safety and Health Administration Code of Federal Regulations (CFR) 29 1910T
- Navy Dive Manual
- Applicable State Department of Labor requirements
- EM 385-1-1, Safety and Health Requirements, Nov 2014 (contractor diving operations)

The requirements for the dive safety plan depend upon whether government or contractor divers will be utilized. OPNAVINST 3150.27C addresses Navy diving policy. A qualified Dive Safety Inspector or District Diving Coordinator must monitor contractor diving operations. Also, the most current version of these manuals must be used.

3.4 Managing Uncertainty

It is important to remember the objective of the RI/FS process is not the unobtainable goal of removing all uncertainty, but rather to gather information sufficient to support an informed risk management decision regarding which remedy appears to be the most appropriate for a given MRS [24]. Some level of uncertainty will always be associated with MRSs, both going into and coming out of the RI. MRS history may be unknown, with many unknown factors such as munitions quantities and types, dud rates, etc. Anticipate that not all RI planning assumptions will be valid and that even the most perfectly planned project needs to consider contingencies.

4.0 TERRESTRIAL REMEDIAL INVESTIGATION

This section provides guidance for implementing the RI for a terrestrial MRS. A terrestrial MRS is defined as a site which is not submerged under water. An MRS that is tidally influenced will manage the region above the mean low low water as a terrestrial site. The RI includes planning for and performing necessary and appropriate investigation activities, developing hazard/risk assessments, and, as needed, performing interim removal actions and/or treatability studies. The RI for a terrestrial MRS is similar to an RI for a terrestrial IR site, with the following general differences:

- The primary hazard/risk for an MRS is an acute explosive hazard, while the hazard/risk for an IR site may be either an acute or a chronic health or environmental effect. An MRS will contain MPPEH and MD. These materials must be formally inspected, certified and verified and then documented either as MDAS or as MDEH. Specific explosives safety requirements are attached to all these materials. Therefore, to address the explosive hazard, an ESS is normally required for an RI at an MRS.
- For an IR site, there are well-established methods for performing risk assessments and quantifying risks. On an MRS, the MEC HA facilitates assessing hazard.
- Use of tools such as Visual Sample Plan (VSP), other statistics-based methods, and the results of the RI intrusive investigation may all be necessary to determine the remedial action area or removal action boundaries.
- The level of characterization required at an MRS is largely dependent on the expected response alternatives (e.g., depth and method of removal) and land use, while characterization at an IR site is based on an iterative evaluation of constituent nature and extent.
- There are myriad sampling and analysis techniques potentially applicable during the RI for an IR site. For an MRS, primary information is available from historical records and facility use information, which is supplemented by geophysical mapping and intrusive investigation for MEC and sampling of environmental media for MC.

The purpose of the RI is to sufficiently characterize the nature and extent of MEC/MC at a MRS to properly evaluate and implement a response action if necessary. An RI will not produce enough data to eliminate all uncertainty associated with the presence of munitions at an MRS.

Figure 4-1 provides a typified roadmap for conducting the RI at a terrestrial MRS.

4.1 Investigation Considerations

4.1.1 <u>General</u>

The project team must keep certain site-specific considerations in mind when implementing the investigation phase of the RI for a terrestrial MRS. These site-specific considerations include:

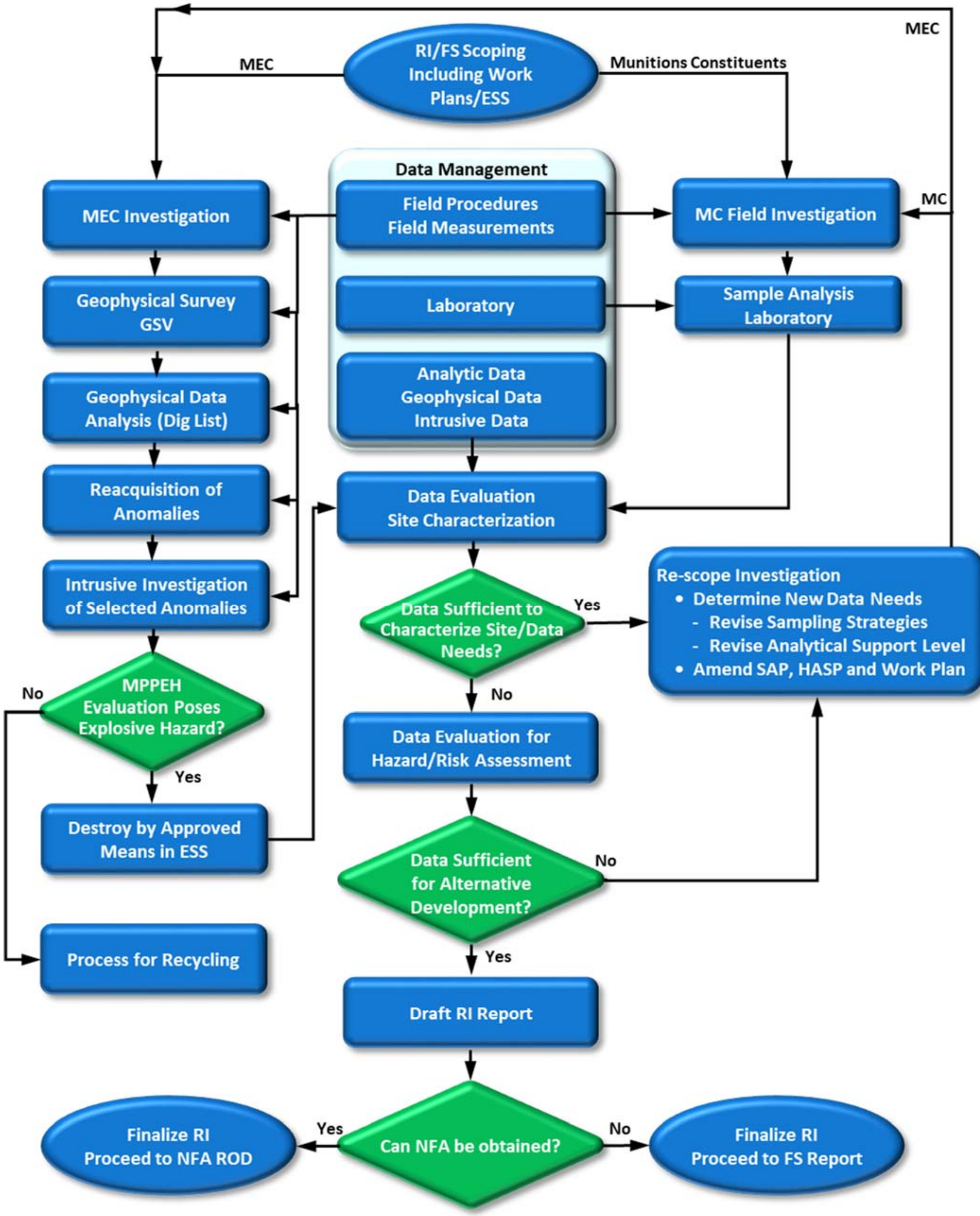

Figure 4-1. Example Roadmap for Conducting the Terrestrial MRS RI

- Topography/terrain
  - There are potential physical sampling and investigation instrument limitations depending on the topography and terrain of an MRS that will influence which platforms are best suited for the sensor.
  - Large, flat areas may be well suited for towed array platforms when geophysical mapping is required, whereas areas with uneven terrain (e.g., rocks and/or ravines) may be better suited for man-portable configurations.

- Geology
  - Magnetometers are particularly sensitive to iron-bearing minerals contained in soils and geologic formations, therefore DGM design must take into account the geology when selecting the best sensor for the site.
  - Regardless of the sensor type, geology can significantly influence the data (e.g., ground mineralization and rocks that are mineralized differently to their surrounding ground/hot rocks). These phenomena need to be identified during the RI and considered in the FS.

- Vegetation
  - Dense vegetation may hinder the physical movement of personnel and equipment across the site. Tree cover may significantly interfere with the ability to acquire and maintain GPS signals which, in turn, impacts the quality of the data and will interfere with the ability to reacquire target anomalies for investigation.
  - Vegetation removal may not always be desired or even be possible (e.g., endangered or threatened species, nesting season, etc.).

Prior to initiating field activities, a thorough reconnaissance and some site preparation are usually required. Site reconnaissance usually begins with a thorough review of site maps to identify and mark areas considered inaccessible. Inaccessibility may be due to many factors and is a subjective determination. The specific activities and the safety of those activities that will be conducted as part of the field work need to be considered when determining accessibility.

There are many landscape and terrain features that can limit accessibility. A common site condition that limits accessibility is the slope of the terrain. The steepness of a slope is only one factor however. The condition of the ground cover may allow for work on steeper slopes if it provides suitable footing for the planned activities. Alternatively, relatively shallow slopes with poor footing may prevent field work activities. Navigating or clearing vegetation will also factor into whether slopes are accessible or not.

Other landscape features that can limit accessibility include water bodies such as lakes, rivers, bogs, marshes, etc. The obvious consideration with water bodies is whether or not they can be safely and cost effectively crossed or navigated.

Information about elevation can also be very useful in planning RI activities in regions where snowmelt has to be taken into account. Conversely, DGM electronics (e.g., sensors and GPS, for example) are extremely sensitive to heat so these activities in desert climates should be planned for cooler parts of the year. Finally, maps are useful to visualize explosives safety EZs and to identify areas and infrastructure that might be impacted by RI activities.

Brush clearance may be required prior to conducting DGM and intrusive investigation. If vegetation clearance is required, hand-held (e.g., chainsaws or brush cutters) or larger mechanical devices (e.g., brush hogs) are used to remove the vegetation. Once removed, vegetation can be left onsite, transported offsite, or managed by mulching and/or burning. Both the vegetation deposition method (e.g., biodegrade, chip, burn, etc.) and vegetation disposal location (i.e. on-site or off-site) should be discussed with local base representatives prior to submittal of planning documents. Vegetation clearance must be performed by laborers trained in general MEC awareness or by UXO technicians. If vegetation removal is performed by non-UXO personnel, then UXO personnel must accompany the brush clearance teams to scout for surface MEC.

It should be noted, hand-raking, manual sorting, removing vegetation with powered or non-powered hand tools using string or plastic cutting surfaces, and using non-intrusive fill interrogation devices are not considered mechanized MEC processing for the purposes of explosives safety siting. Depending on the proposed operation and MGFD expected, operations involving hand-held vegetation cutting devices with metal blades or other cutting surfaces shall be considered mechanized MEC processing operations, unless determined otherwise by NOSSA or MARCORSYSCOM, as appropriate.

If DGM is to be conducted during the RI (over a small area, for instance), then prior to the DGM, surface removal would normally be conducted (unless already conducted through prior operations at the site) to remove items that could mask underlying objects. Surface removal is generally accomplished by a UXO technician team leader and a team of UXO technicians identifying metallic items visually and searching brush or clumps of grass with a metal detector. The surface items are generally removed immediately and staged for later pickup and removal from the grid and MEC are flagged for later disposal. Surface removal is not typically performed ahead of transect DGM. UXO technicians must be assigned to move ahead of DGM teams to scout for surface MEC, provided the DGM teams are staffed using non-UXO personnel.

4.1.2 Sampling Design and Rationale for MEC

Different survey designs can be used depending on the goals of the RI/FS for the MRS. If further geophysical surveys are warranted, probabilistic survey approaches can be used to investigate for MEC or to look for large objects of interest (e.g., a target area or a disposal trench). Additionally, AGC methods may be implemented if site conditions are suitable (e.g., areas are not saturated with metallic debris). AGC can provide an accounting of subsurface items accompanied by removal of all selected TOIs or removal of a subset of TOIs to verify target selection criteria. At the conclusion of sampling, the project team should have a clear picture of the spatial distribution of MEC at the site, precise information on the depths of MEC, areas which are inaccessible to DGM/AGC and areas that may be inaccessible to intrusive investigation (e.g., wetlands, areas of sensitive habitat, etc.). Sampling design can also be influenced by the estimates of the penetration depth of the munitions. Some munitions tend to not penetrate the ground surface (e.g., grenades), while others may penetrate or be buried through disposal operations that are beyond the ability of the instrument to reliably detect them.

Probabilistic survey approaches include the following:

- Fixed-pattern grid
- Random-pattern grid
- Hybrid-pattern grid
- Mini grid
- Radial
- Transect
- Cross-hatch
- Meandering path

Fixed-pattern Grid

In a fixed-pattern grid survey, regular survey grids are laid out over a fixed percentage (often 10%) of an area. The fixed-pattern grid survey is not frequently used.

Random-pattern Grid

In the random-pattern method, a statistical approach is used to randomly locate survey grids in an area. Grid size and shape are determined based on site characteristics, such as terrain and vegetation, as well as on the particular instrumentation to be used. The total area to be investigated is determined using a statistical tool to provide adequate confidence in the survey findings.

Hybrid-pattern Grid

The hybrid-pattern grid method is essentially the same as the random-pattern grid method, but some additional survey grids (i.e., generally approximately 20% more grids) are included to fill potential data gaps. The hybrid-pattern grid method is most often used to ensure that an area known to contain MEC receives more survey coverage.

Mini Grid/Full-coverage Grid

In the mini grid/full-coverage grid method, a small grid pattern is surveyed within an area known to contain MEC, typically to characterize the specific type and more precise extent of the MEC related debris in that area. Normally this is done to determine depth and density of the MEC related debris and any other metallic debris in area. Usually mini-grids will remove all metallic surface debris to a certain size specification and perform 100% intrusive investigation of the anomalies within the grid, but this change depending upon project goals and technology used. This data can then be used to estimate the level of effort and cost for any follow on work.

Radial

In the radial path method, a pattern is surveyed by walking out from a single established survey point in a number of radial lines. As with the hybrid-pattern grid method, the radial method is most often used to ensure that an area known to contain MEC receives more survey coverage.

Transect

In the transect method, geophysical surveying is completed along a series of parallel and evenly spaced transect lines that are generally oriented perpendicular to the long axis of the area being investigated. With sufficient density of the transect lines, the survey would approach 100% coverage; however, the line spacing is often much greater in the transect approach than would be required to accomplish 100% survey coverage. The transect approach is often used during the first geophysical survey at an MRS. Transect surveying is optimal at sites with easy terrain and no significant vegetation. Statistical tools can be used to aid in transect spacing design to help identify target areas.

Cross-Hatch

In the cross-hatch approach, geophysical surveying is conducted in a transect pattern and then the pattern is repeated along transects rotated 90 degrees from the original transects. As with the transect approach, the spacing of the transects can be varied to obtain differing levels of data coverage.

Meandering Path

In the meandering path approach, the geophysical survey equipment is fitted with an accurate navigational instrument (i.e., typically GPS), and the survey team walks an essentially random and circuitous path across the MRS. Multiple paths are surveyed until the data coverage is equal to what would have been required in some other statistical survey approach (e.g., fixed-pattern grid). The meandering path approach is optimal for sites with difficult terrain and heavy vegetation (i.e., it reduces the cost associated with vegetation removal). However, the meandering path method also makes it more difficult to reacquire specific data points.

Survey Pattern Density and Spacing

When implementing a geophysical survey, the density and spacing of survey lines must be sufficient to ensure proper site characterization to determine nature and extent of MEC, and to subsequently allow the assessment of risk and the planning for and implementation of a response action. Full (i.e., 100%) coverage of an MRS is typically not required to fulfill the basic or even optimum RI/FS data needs. Remember that the Site Inspection phase did not perform 100% coverage to identify the boundaries of the site, and the RI also should not need 100% coverage to meet the RI goal of determining nature and extent.

Geophysical survey density and spacing can be determined using a modeling program or by using impact probability data and horizontal fragment distances from various military publications. Visual Sample Plan (VSP) and the module UXO Estimator are two statistical tools are commonly used to support this type of decision making.

VSP

VSP is a software tool that supports the development of a defensible sampling plan based on statistical sampling theory and the statistical analysis of sample results to support confident decision making. VSP contains a UXO module that can be used for the following functions:

- Determining the transect spacing needed to locate a MEC target area with a specific degree of probability.
- Assessing the probability of target area traversal based on actual transect pattern.
- Approximating the probability that a target area of a specific size and shape would have been found if another transect pattern had been used.
- Assessing the degree of confidence in MEC presence.
- Locating and marking MEC target areas based on elevated anomaly density.
- Geostatistical mapping of anomaly density and delineation of target areas.

VSP is most appropriate for delineating areas that are known to contain areas with a high density of MEC (e.g., target areas), the precise location of which may not be known. VSP has been modified to incorporate the same statistical equations used in UXO estimator. These equations have the same limitations discussed under the UXO Estimator section. VSP can be downloaded at http://dqo.pnl.gov/vsp/vspdesc.htm.

USACE UXO Estimator

The USACE UXO Estimator module, which is a module within VSP, is described in EM 200-1-15 Military Munitions Response Actions [25]. The estimator can be used to develop an investigation plan for an MRS and to estimate the amount of MEC potentially present in an area that is not suspected of containing target areas. The USACE UXO Estimator assumes that there is only limited use of MEC in an identified area, and can be used to determine levels of statistical confidence related to measured MEC density and to perform actual statistical tests concerning such density. The USACE UXO Estimator is appropriate where it can be assumed or inferred that only limited MEC is in an area (a maneuver area for example may be considered appropriate depending on the CSM for the site). RPMs need to consider the costs of achieving a specific statistical confidence when using this tool.

Phenomenological Factors

The evaluation of phenomenological factors at an MRS can provide valuable data to support the selection of both appropriate survey technology and survey design. Phenomenological factors include:

- Munitions type, orientation, and likely depth of burial;
- Distribution of munitions debris;
- Topography;
- Soil and rock types;
- Vegetation type and density; and

- Cultural features (e.g., utilities, structures) and the physical characteristics of these features (e.g., construction materials).

The premise for considering phenomenology is that the physical and cultural attributes of a site are significant influences on what a geophysical instrument measures. The phenomenological evaluation is not a routine step for the RI of an MRS due to time and cost constraints, but may provide valuable information to facilitate sensor selection, survey approach, and data interpretation. One example of considering phenomenological features occurred at one site where the munitions of concern were old cannonballs. The use of metal shoring at the site did not allow the use of traditional magnetometers or Electromagnetic Induction (EMI) sensors. In this case, ground penetrating radar was the instrument used to identify anomalous features. Ground penetrating radar was also used at another site to detect where plastic landmines were emplaced because magnetometers and EMI sensors would not be effective. These examples show where the sensors that are normally the most effective on a munitions response project would be ineffective and that the evaluation of phenomenological features aided the project execution.

4.1.3 Sampling Design and Rationale for Munitions Constituents

MC contamination can result from munitions shell breaching, leakage, corrosion, or low-order detonations. In a low-order detonation, the munition filler is only partially detonated and the components of the item may be scattered either as MC or still partially encased in the munitions body. High-order detonations produce very little MC residue.

Characterization of MC at an MRS is generally equivalent to the characterization of chemical contaminants at an IR site, as it involves sampling of environmental media (e.g., soil and GW) and the analysis of samples to determine the nature and extent of MC impacts. Specific MC sampling requirements for an RI/FS are determined on a MRS-specific basis, in accordance with the CSM and through the systematic planning process. The purpose of the MC characterization is to assess the nature and extent of MC, define the risk to human health and the environment, and aid in developing remedial alternatives. While not the primary purpose of an MRS RI/FS, sampling and characterization of incidental, non-munitions related contaminants may be a component of an MRS action. Any sampling done to characterize MC (or incidental, non-munitions related contaminants) must be conducted in accordance with the project SAP and should use anomaly avoidance techniques.

The sampling plan for MC should be based on the findings of the MEC RI whenever possible. The MEC investigation should confirm the presence of a MEC/MD source prior to initiation of MC sampling to ensure that the MC sampling addresses the areas most likely to be contaminated. The focus of MC sampling should be on areas of concentrated munitions use and sampling units should be placed in those areas.

During characterization activities, MC may be found at concentrations that actually pose an explosive risk. This condition is not typical for ranges, but may occur at munitions operating or production facilities. If MC is determined to pose an explosive hazard, it is considered MEC and all approaches consistent with the investigation of MEC must be implemented to ensure the safety of personnel, including protective measures and potentially alternative sampling approaches. In addition, when operating in areas of a known or potential explosive hazard associated with MC, a safety analysis is needed for sampling/handling equipment to ensure that forces are not initiated that could propagate a detonation.

In addition, it may be necessary to conduct sampling for MC around/beneath MEC removed as part of the MEC characterization activities during the RI, and/or after detonations performed at an MRS (i.e., soils in a detonation pit and soils ejected from a detonation site) during the MEC characterization activities to determine the presence of residual MC from those detonations. It is important to consider the actual number of sampling stations, as it is likely not necessary to sample around/beneath each and every MEC item removed and at every detonation site to adequately characterize residual MC. Notably, high-order detonations and BIP typically yield MC residuals at concentrations that are orders of magnitude beneath relevant criteria. Sampling of specific MEC items or BIP locations should be limited, as that data is of limited usefulness to evaluation of risk associated with exposure to MC.

Additional information on MC characterization is available in EPA's *Site Characterization for Munitions Constituents* [27] and USACE EM 200-1-15 Technical Guidance for Military Munitions Response Actions [25].

During the investigation of MC, soil is generally the environmental medium of interest. Sampling designs for characterizing MC in soil include discrete, composite, and incremental sampling.

Discrete sampling is conducted to provide point concentrations at specific coordinate locations. Given the typical heterogeneity of MC at an MRS, sampling results from discrete sampling are not often reproducible and can yield significantly different results in adjacent sampling points. Because of the heterogeneity of MC at a given site, there are concerns about using discrete samples to represent the average concentrations in soils. Studies have shown that estimating a mean based on just a few discrete samples will result in a mean value that is biased low [28].

Composite sampling has been implemented at munitions sites, relying on a "spoke and hub" approach, where five- or seven-increment samples are obtained from the center point plus four or six surrounding points forming a "box" or "wheel" sampling design. Results of this type of sampling have confirmed the non-reproducible nature of discrete sampling.

Incremental sampling is conducted by defining a smaller sampling/decision unit (DU) based on the overall size of the MRS. The sampling/DU may only be a few square feet in size, but typically produces significantly more representative data and is often the preferred characterization approach for MC at an MRS.

In incremental sampling, 30 or more (sometimes 50 to 100) individual subsamples are collected over the sampling/DU, and are combined to form a single sample that is representative of the sampled area. Samples can be collected using a systematic-random pattern or a totally random pattern. However, a systematic-random pattern is recommended rather than a totally random pattern that may over- or under-represent various areas of the sampling/DU. Figure 4-2 shows a stylized representation of how subsamples would be collected using a systematic-random pattern in a sampling/DU.

Specific guidance on incremental sampling is described in:

- EPA SW8330B method guidance document; and [28]
- Incremental Sampling Methodology, ITRC 2012.

Sampling/DU at an MRS will depend on the overall site layout, site-specific factors, and the required end use of the data. For a former arms range, sampling/DU could include the target area, the overshot and undershot areas, the firing point(s), and the range fan area. DUs should be established based on a good understanding of the CSM (surface topography, preferential pathways (ditches, wash outs, etc.), paved/unpaved areas, past, present, and/or future land use, type of media (sediment versus surface soil, surface soil versus berm-soil etc.), and the type of environment (grass, forest, wetland, barren areas, etc.). Establishment of a very good sampling design (appropriate placement of DUs) helps to not only characterize surface soil for assessing the lateral extent of surface soil contamination but also to identify remedial action areas. Poor placement of DUs or DUs that encompass several site features may result in dilution of COPCs in the sample.

The sampling/DU size will vary depending on the manner in which the deposition has occurred at the MRS. For example, at an artillery range firing point the residue is dispersed over a fairly large (e.g., 10,000 m^2) area from a single training exercise. Near a low order detonation, the size of the impacted area can be rather small (e.g., 25 m^2). A factor to consider when choosing the size of the sampling unit is what constitutes a manageable sample for field and laboratory operations without compromising data quality. These parameters coupled with range use records, range function and design, surface conditions, and the DQOs should all be considered when deciding where to sample and the size of the sampling/DU. In some cases, the area impacted by an activity is so large that it must be divided into multiple sampling/DU.

An example of where this was done was at Waikane Valley Impact Area. In that case, three Areas of Concern were each subdivided into three DUs. Each DU was subdivided into 30 grids from where one soil increment was collected and combined to form the multi-increment primary sample. The rationale for selecting the DU was based on existing knowledge of known or suspected MEC and MC contamination, as well as areas topographically downslope from potential source areas, where MC may have migrated.

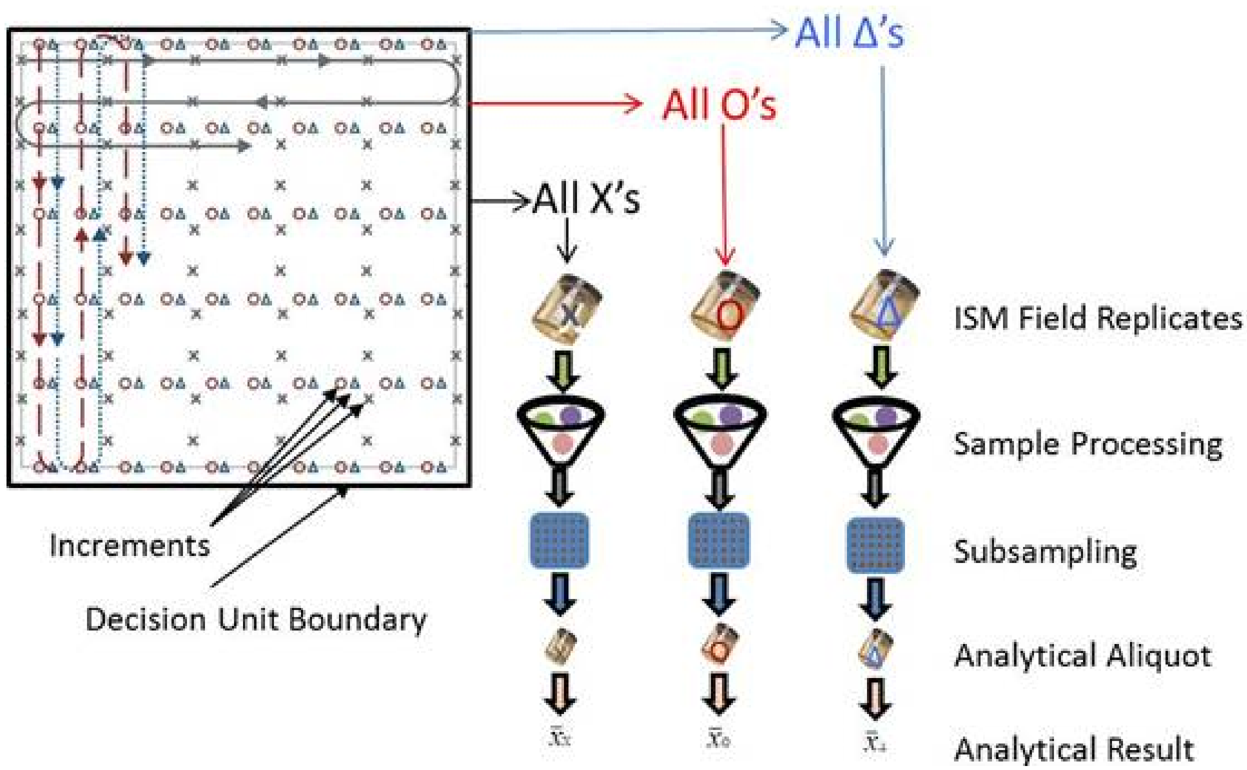

Figure 4-2. Stylized Approach to Incremental Sampling

Table 4-1 summarizes the MC sampling design considerations for specific MRS types based on Protocols for Collection of Surface Soil Samples at Military Training and Testing Ranges for the Characterization of Energetic MCs [29] from the USACE Engineer Research and Development Command (ERDC) Cold Regions Research Engineering Laboratory (CRREL). Additional details related to sampling design can be found at:

- The NAVFAC Portal
- The Fall 2008 Remediation Innovative Technology Seminar "Sampling Design" on the MR Reference DVD

If significant releases of MC are suspected, GW sampling should also be considered. This decision should be based on the depth to GW, the type of MC and likelihood of MC transport to GW, the magnitude of the source contamination, and potential receptors. Similarly, if surface water is located at the MRS and receives runoff from MC source areas, surface water and sediment sampling should be considered.

An important step in the RI is the determination of background concentrations of chemicals. Natural or ubiquitous anthropogenic levels of metals, polycyclic aromatic hydrocarbons, and even chemicals such as perchlorate may exceed screening levels or regulatory limits that are commonly applied for screening purposes or for response action decision making.

Table 4-1. RI MC Sampling Considerations for Various Range Types

RANGE TYPE	DESCRIPTION	TYPICAL WEAPONS USED	TYPICAL ENERGETIC MC	SAMPLING DESIGN	ADDITIONAL CONSIDERATIONS
Hand grenade range	Hand grenade ranges are small throwing bays, sometimes divided into several courts. Practice is to throw grenade from behind a fortified earthen wall into an impact area.	M67 fragmentation grenade	Composition B (RDX, TNT) MC should include degradation products and impurities of RDX and TNT.	RI samples target the area between the front bay to the impact area, all along the impact area's width. Sample depth is dependent on the depth of penetration for a hand grenade; the sample depth should reflect this depth of penetration. For areas <100 m^2 recommend 30 or more increments to prepare incremental samples along a systematic grid. For areas $\geq$100 m^2, recommend 50-100 increments, depending on site size. Number of samples will be agreed to during the systematic planning process. Within area with the highest crater density, at least five depth profiles should be collected in 10-cm intervals down to a depth of at least 30 cm.	When courts are not separated by barriers, sample as single DU. Deposition is normally at surface; however, with cratering and range management, this will vary.
Anti-tank rocket range	Rocket projectiles are fired from shoulder-mounted tubes.	66 mm M72 Light Anti-Armor Weapon (LAW) AT4 rockets	Practice rounds include propellant, but no high explosive warhead. LAW rocket warheads include octol (HMX, TNT) with a tetryl or RDX booster, M7 double-base (nitrocellulose [NC]/ nitroglycerine[NG]) propellant, potassium perchlorate, and carbon black.	For the target area, RI samples should be taken in areas where most munitions residues are expected to be found (within 25-m radius of each target). 100 increments of the top 5 cm are recommended; more increments may be required for areas greater than 25-m radius. A segmented halo design can establish RI samples within the individual segment areas. For the firing point, recommend a single 100-increment sample in a rectangle 30 m wide and running the entire length of the firing line. Collect samples from top 2.5 cm. Depth profiles can be collected to assess whether subsurface migration of dissolved propellant-related compounds has occurred.	Explosive and propellant residues are present in front of and behind the firing line and around targets.
Artillery/Tank/Mortar range	These range types are typically the largest training ranges	155 mm howitzer 105 mm artillery projectiles 120 mm tank projectiles 81 mm, 60 mm, and 120 mm mortar rounds Various smaller munitions	High explosive components include TNT, Composition B, tetryl, octol, etc. Single-based (NC; 2,4- Dinitrotoluene (DNT)), double-based (NC/NG), and triple-based (NC/NG/NQ) gun propellants were used.	Sampling between 100 m from the firing position to within 500 m of targets or heavily cratered area not generally recommended. For impact areas, recommend 100-increment samples from the top 5 cm in a 50 × 50-m sampling/DU centered on each target. Profiling sampling only recommended in areas where low-order detonations have been found. Within the firing area, sampling/DU of 50 × 50-m or smaller can be used for collecting 100-increment samples from the top 2.5 cm; multiple sampling/decision areas are often required.	Low-order detonations of rockets/mortars pose the greatest risk for contaminant point sources in impact and target areas. Propellant residues at firing points are often found downrange where excess propellant was burned.
Bombing range		Various	Various	Apply same principles for artillery impact ranges.	
Demolition range		Various	Various	Apply a grid within the OB area, collecting an RI sample from the top. Recommend 10 × 10-m sampling units and 30-increment samples from the top 10 cm in each unit. Depth increments from at least five profile samples should be collected in areas where the surface has been discolored or where demolition craters had been located in the past.	
Small arms range		Various	Various	At firing points, recommend 100-increment samples collected from the firing line to a distance of 10 to 20 m depending on type of small arms used. The entire berm face can typically be considered a sampling/DU. Soil samples submitted to the laboratory should not include lead shot, or intact or fragmented bullets. However, any lead fragments contained in the sampling volume should be collected and weighed in the field and/or in the laboratory. The laboratory should also be instructed to remove any visible lead fragments which pass sieving, prior to extraction.	Grinding of the samples is a project team decision; if performed the team should understand its ramifications, including potential pitfalls.

[23, 27]

Note: This is not a comprehensive table for MRSs as there may be other types of sites and munitions that may need to be considered.
Detailed information is not included in this table. For detailed information regarding RI sampling, refer to USACE ERDC [29] and EPA [27].

Some available resources for implementing background investigations and determining background concentrations are:

- NAVFAC Guidance for Environmental Background Concentration Analysis
  - Soil (UG-2049-ENV)
  - GW (UG-2059-ENV)
- EPA Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites (540-R-01-003)
- EPA Data Quality Assessment: Statistical Methods for Practitioners (QA/G-9S)

4.2 Munitions Detection Technologies

4.2.1 Basic Detection Principles

The first step of the geophysical survey for MEC is selecting the appropriate investigation technology. MEC detection technology is used to perform three distinct types of operations:

- MEC/MPPEH Surface Sweep Operations — systematic search of a specific area using a handheld instrument in real-time to detect and locate surface MEC/MPPEH.
- DGM Operations — terrestrial systems collect georeferenced DGM data over a specific area and process that data to aid in boundary determination and footprint reduction, and to identify and report the locations of subsurface anomalies for later reacquisition, excavation, and removal action.
- AGC Operations – AGC systems are used in terrestrial environments to collect georeferenced geophysical data either in a dynamic or cued mode. The data collected provides intrinsic properties of metallic items that allow the analyst to determine whether the item is munitions like (possible TOI) or non-munitions like (clutter). These systems, in most cases, reduce the number of subsurface anomalies for later reacquisition, excavation, and removal.
- MEC/MPPEH Reacquisition Operations — terrestrial anomaly reacquisition operations locate subsurface anomalies previously detected through sweep or DGM/AGC operations in support of excavation and removal and to identify and report the locations and depths of subsurface anomalies for any follow actions.

A MEC detection system is composed of four main elements:

- Geophysical sensor
- Sensor platform and transportation system
- Positioning and navigation system
- Data processing system.

The geophysical sensor is generally the term used to describe MEC detection systems, but other elements are just as critical to the success of the overall system. The survey platform deploys the geophysical sensor and not only governs the terrain in which the system can be operated, but is also a critical factor in sensor performance. The positioning methodology determines the geophysical sensor's geographic location at each data point recorded during a survey. The accuracy of the survey location determines the ability to identify anomalies in the data (through the gridding process) and to position those anomalies for reacquisition. Review of the navigation data provides a record of data coverage on the site and shows areas missed (called holidays) or intentionally not covered (e.g., inaccessible areas). The data processing system ultimately determines how data are managed and how targets are selected and interpreted.

Advanced geophysical sensors can be utilized in either dynamic or cued mode. Dynamic mode, is similar to traditional DGM methods where continuous data is collected while the system is moving over a path, although more data is collected with AGC sensors. The richer data set allows for the identification of sources as opposed to anomalies and a more robust detection methodology. This process provides refined source locations, as well as estimates of features related to the source object size and wall-thickness. This enables the detection threshold to be tied directly to the smallest TOI and targets that are smaller and/or thin-walled are easily excluded. Additionally, this process provides more precise locations than the traditional DGM methods and is able to identify separate sources with overlapping signatures. Cued mode is placing the sensor at a specified geographic location of a previously identified anomaly or source to collect additional geophysical data to allow better estimates of features related to the source object size and wall-thickness than can be provided by dynamic mode.

The selection of the most appropriate MEC detection technology is not a simple task for two reasons: (1) there is not a currently accepted "best" tool that offers a high degree of effectiveness, ease of implementation, and cost effectiveness in every situation; and (2) the "best" detector in one geologic, topographic, and vegetative environment may not work well in a different environment.

For more information on MEC detection technologies, see the resources in section 3.1.5 and one or more of the following sources:

- DoD's ESTCP
- NAVFAC's portal
- ITRC UXO Documents Web site: http://www.itrcweb.org/teampublic_UXO.asp
- EPA Military Munitions and UXO Web site: http://www.epa.gov/fedfac/documents/munitions.htm

Analog geophysical tools produce an audible output, meter deflection, and/or numeric output, which is interpreted in real time by the instrument operator. Analog tools include handheld metal (EMI) detectors, and ferrous locators (magnetometers). The operator holding the sensor serves as the survey platform, positioning system, and data-processing system. UXO technicians have used analog tools ("Mag & Flag" or "Mag & Dig") for many years to screen areas for TOI and conduct clearance activities. When an anomaly is detected, the location is marked immediately by placing a small flag in the ground. Analog tools can be effective in certain applications because they provide real-time field observations, anomaly locations can be manually flagged at the time the signal is observed and excavated immediately following the survey, and there are few constraints due to vegetation or topography. Their use is limited by the following, however:

- Data quality depends on human factors that cannot be measured (including attentiveness/distraction and hearing ability).
- Decisions are made in the field based on the operator's judgment.
- The instrument response provides no information regarding the source of the anomaly; therefore, it is unable to distinguish munitions from non-hazardous debris or geology.
- The probability of detection, for munitions of concern, has been demonstrated to be between 50 and 72% (ITRC 2006).
- No permanent electronic record (of either location coordinates or instrument response) is provided; therefore, no auditable decision record exists.

Digital geophysical tools measure the same physical properties but also digitally record and geo-reference data to measurement locations. All digital tools provide a permanent electronic record of the data, ensuring data reproducibility and permitting after-the-fact data analysis. Data can be interpreted immediately or at any time after data collection is complete. DGM instruments also include advanced EMI sensors that provide information on the physical attributes of the anomaly source, enabling the classification of anomalies as TOI or non-TOI. Their use is limited in areas where vegetation or topography limit access or impede the function of positioning systems.

4.2.1.1 Sensors

A broad range of MEC sensor technology is commercially available. Three main sensor technologies are used for MEC detection:

- Magnetometers
- Electromagnetic induction
- AGC

Magnetometer

Magnetometers and gradiometers are passive sensors (meaning that they do not have an active transmission of electromagnetic energy) that measure changes in the Earth's magnetic field caused by ferrous and ferromagnetic materials. Ferrous items create irregularities in the Earth's magnetic field and may contain remnant magnetic fields of their own. Magnetometers measure these irregularities. Magnetometers/gradiometers can only detect ferrous metal items. The main advantage to a magnetometer is its ability to detect large items at deep depths. Some vendors of magnetometers and gradiometers include Schonstedt, Geometrics, and Foerster.

Three of the most common types of magnetometers/gradiometers are the optically-pumped alkali (i.e., cesium or potassium) vapor, proton precession, and fluxgate detectors. Alkali-vapor magnetometers are also known as atomic-vapor magnetometers.

Optically-pumped and proton precession magnetometers measure the total intensity of the geomagnetic field at the point of measurement, and operate at the atomic and nuclear level, respectively. These magnetometers are frequently used in mapping munitions sites because they have a high data density and, hence, high data resolution.

Fluxgate magnetometers generally measure the vertical component of the geomagnetic field along the axis of the instrument as opposed to the total intensity of the geomagnetic field. They are used primarily to sweep areas to be surveyed. (The term sweep refers to the back-and-forth motion used to move the sensor from side to side as the operator moves down a designated sweep lane.) They are commonly used in locating munitions items during reacquisition. These magnetometers are relatively inexpensive, locate magnetic objects rapidly, and are easy to operate. The disadvantages of these types of magnetometers are that most do not digitally record the acquired data and the readings can be inaccurate if the instrument is not used properly.

The falloff in signal in a magnetometer is a function of the distance between the sensor and the target ($1/R^3$), as shown in Figure 4-3[30]. For electromagnetic devices, active systems with

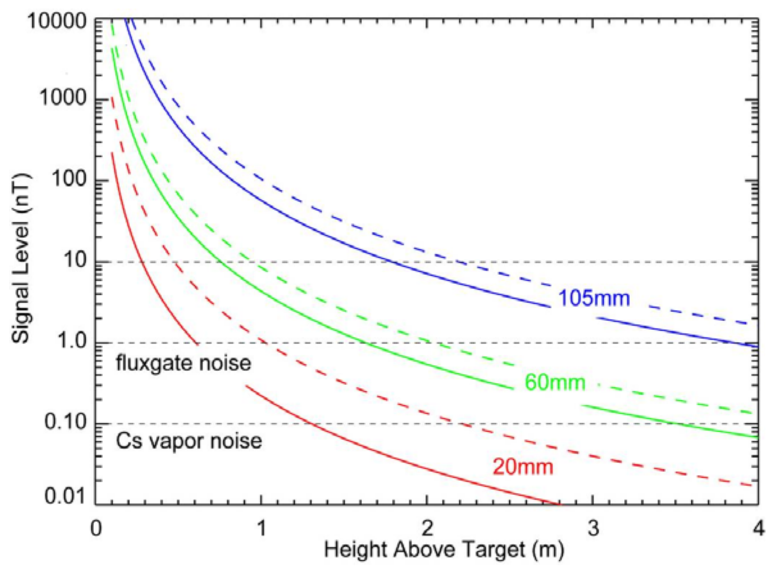

Figure 4-3. Typical Magnetometer Response Curves

losses in both the transmit and receive directions, the falloff is even more severe. On Figure 4-3, the solid curves represent the targets oriented with long axis horizontal, and the dashed curves with the targets oriented with long axis vertical. Some magnetometers require proper orientation to the Earth's magnetic field [26]. The vertical orientation of the long axis of the target is the more favorable orientation for detection. Background noise (geologic noise) also interferes with detection by reducing the signal to noise ratio. As the noise floor increases, the distance at which an object can be detected will decrease. As typical field conditions degrade and the background noise exceeds the quality of the sensor data, the performance degrades. Some of these issues can be overcome with an electromagnetic induction EMI sensor.

EMI

EMI involves an active sensor that induces electrical currents in nearby conductive materials. The electrical currents generate a secondary magnetic field (eddy currents) around the metallic object that is subsequently measured. There are two basic types of EMI methods: frequency domain and time domain. They differ in the way they measure the decaying currents. Frequency-domain instruments measure the frequency of the returning signal, while time-domain instruments measure the signal along a timeline. EMI sensors can detect both ferrous and nonferrous items, and are less susceptible to geologic interference (e.g., magnetic soils). Electromagnetic sensors cannot detect deeply buried items as well as a magnetometer, however, they are effective in detecting small, shallow metallic items (e.g., 20 mm, 37 mm) that are ferrous and nonferrous. EMI sensors are also sensitive to height above the target. The signal falls off at the rate of $1/R^6$ distance between the sensor and the target [30].

EMI instruments are versatile and can be used in both digital and analog modes. In the digital mode, data are stored for later processing and analysis by a geophysicist. In analog mode, the output of the instrument is analyzed by the operator through interpretation of an audio signal. EMI data must be adjusted for sensor artifacts, background, and geology.

A time-domain EMI (TDEMI) sensor detects buried metal objects by measuring the electrical response to a transmitter coil-induced pulsed wave at several time intervals. Longer time intervals between transmissions are capable of detecting objects to greater depths. TDEMI instruments are available from several commercial vendors, including Fisher, Geonics, Schiebel, Vallon, and White. One specific example of a TDEMI instrument that is widely used in the munitions response industry is the Geonics EM61-MK2. The Geonics EM61-MK2 can be configured in multiple arrangements and carried by multiple platforms (e.g., hand-held, cart, or ATV). Under ideal conditions, the EM61-MK2 instrument is capable of detecting large munitions items at depths up to 10 ft below ground surface (bgs). It can detect small objects, such as a 20-mm projectile, at a depth of 8 inches bgs.

A frequency-domain EMI (FDEMI) detects buried metal objects by measuring the electrical response to a continuous output of electricity at a particular frequency or multiple frequencies. FDEMI instruments are available from several commercial vendors, including Fisher, Geonics, Geophex, Schiebel, and White. Two specific examples of a FDEMI instruments that have been used in the munitions response industry are the Geonics EM31 and the Geophex GEM-3.

Advanced Geophysical Classification

Advanced EMI sensors that perform AGC function on the same principles as standard EMI sensors (e.g., transmitter pulse followed by measurement of the eddy currents). The AGC sensors measure many more time gates, 20 to 60 or more, and measure the eddy currents in all three axes, whereas the standard EMI sensor only measures the response in one axis and with 4 time gates. Figure 4-4 illustrates the principle. AGC sensors are discussed in more detail in section 4.4.

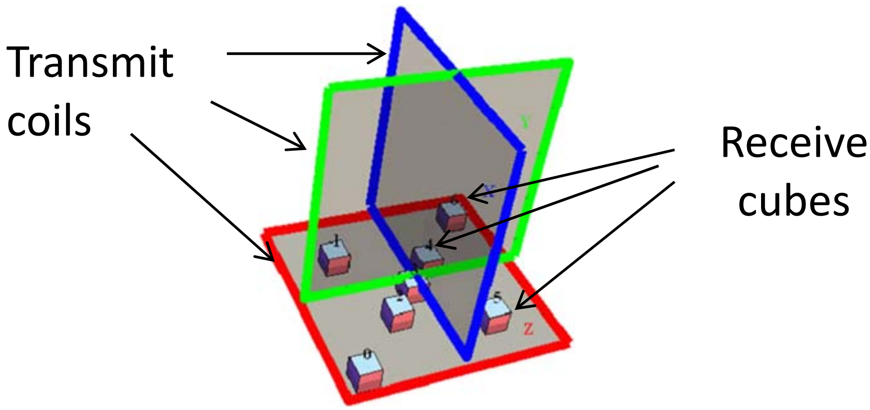

Figure 4-4. Advanced EMI Sensor Transmit/Receiver Configuration

Specialty Sensors

One final category of sensors that may be used on MEC sites are specialty sensors such as synthetic aperture radar (SAR), light detection and ranging (LiDAR) and infrared, typically in airborne platforms. These technologies are generally more useful for the site inspection phase rather than the RI phase. In selected situations where data are needed to help characterize the site in the absence of other documentation, these technologies may provide valuable information about the site. SAR collects high resolution data about metallic objects at the near surface. LiDAR works like radar but only uses laser light to reflect off of the Earth's surface instead of a radio wave.

LiDAR and SAR generate high resolution three-dimensional images of the surface which can be analyzed for craters, bunkers and other indications of use as an impact area. Infrared is infrared detection and senses the heat differential between metallic objects and the Earth's surface. Infrared provides high resolution images of metallic objects on the surface. These specialty technologies are expensive and are not economical unless the remediation area is quite large. Coverage can be in hundreds of acres per day.

Other technologies have been used in various configurations for munitions detection, including the following:

- Sub-audio magnetics: a patented methodology that uses a total field magnetic sensor to simultaneously acquire magnetic and electromagnetic response.
- Dual-sensor systems: a combined magnetometer and EMI system.
- Multi or hyper-spectral imagery: a typically airborne technology that uses broadband cameras to acquire spectral signatures to identify material composition and size.

- Sonic systems
- Explosive “sniffers”
- Neutron backscatter sensors

Each of these technologies is currently characterized by less proven effectiveness, challenges to field implementation, and issues associated with cost as compared to magnetometer and EMI, which are generally the industry-standard approaches to investigate a MRS.

4.2.2 Platforms

Various platforms are available to deploy geophysical sensors. The following are the basic classes or types of sensor platforms:

- Handheld
- Man portable
- Towed array
- Airborne

Handheld systems are typically operated in analog mode and do not log data. These systems are best applied in areas where digital data collection is not possible (e.g., terrain can’t be traversed with a man-portable system). Unlike digital systems where anomalies are selected based on a threshold, handheld systems cannot be so easily adjusted and so the number of anomalies selected for investigation is typically much higher than with digital systems (i.e. higher false positive rate). There is also a potential for operator error and gaps in coverage to go unnoticed with these systems used in analog mode.

Man portable systems have production rates of approximately one acre per day, per unit. Magnetometer systems can be configured in either a vertical (e.g., sensors placed one directly above the other) or horizontal (sensors spaced horizontally) gradiometer configuration. Magnetometers can also be configured with up to four sensors abreast on a cart which can be pushed or pulled. Electromagnetic sensors (typically EM61-MK2 – 0.5 m × 1 m coil) can be wheel mounted and pulled by one individual or mounted between two non-magnetic poles (stretcher mode) and carried by two individuals.

Towed array systems typically consist of several electromagnetic or magnetic sensors configured in an array which is towed behind either an off-the-shelf ATV, tractor, or a specially designed low signature tow vehicle. These systems have higher production rates due to higher speed and/or more sensor coverage per pass. They can be very effective in larger, flatter and more open areas that are obstacle free. A typical production rate for towed array systems can be up to 10 acres or more per day.

Airborne systems can provide coverage of large areas during the site inspection. However, airborne systems are expensive, may be rendered inapplicable by certain site conditions (e.g., tree canopy or extreme topography), and are generally less capable of detecting smaller anomalies due to being operated higher above ground level (typically 1.5 m to 3 m).

4.2.3 Positioning

DGM on a MEC site would not be possible without accurate positioning of the data. The sensors are typically logging data at somewhere between 10 and 20 times per second per sensor. At the same time, the sensor is being moved across the ground. In order to provide the proper spatial relationship of one data point to another, it is imperative to know exactly where each data point was collected. The advanced classification sensors discussed in section 4.4 collect much more data that also requires accurate positioning. This positioning can be accomplished two ways: (1) through a technology solution or, (2) through fiducial marks placed in the data and referenced to the ground.

The most common technology solution used to position data is GPS. A GPS receiver is carried with the antenna a known distance (X, Y and Z) from the sensor. The receiver calculates and reports position once per second and these data are recorded either independently or, more commonly, concurrent with the geophysics data providing an accurate position for each one second of data collected. If the GPS data are collected separately, they must be merged with the geophysics data based on the timestamp in the geophysics data. The cost for GPS is low and its inherent accuracy has improved dramatically where centimeter accurate positioning can be achieved. Accurate positioning must take into account all the sources of error in determining position (e.g. yaw, pitch and roll motion of the vessel), not just the accuracy of the GPS so the final position accuracy can be degraded. GPS is an appropriate technology in areas where a good view of the sky is not obstructed by vegetation, trees, close mountains or buildings.

Techniques to improve the accuracy of GPS for mapping exist. Correction of bias factors may be accomplished in real time, using a real time kinematic (RTK) GPS system, or through post processing (PP). Both RTK and PP systems use a base station, set up on a known point, which then transmits corrections to a roving GPS unit via radio or satellite (RTK), or records base station data that is used to apply differential corrections to the recorded roving GPS data (PP). RTK GPS is the most accurate and common form of GPS surveying performed for MEC detection. RTK GPS surveys can be accurate to within 3-10 cm.

The United States Coast Guard Navigation Center operates the most widely used real-time DGPS service, using two control centers and a network of broadcast stations, or “beacons”. Real-time differential correction requires a GPS receiver that is tuned to the frequency of the broadcast real-time correction message. When a real-time correction message is present, the receiver will apply the differential correction to GPS data concurrently with the collection of field data. An effort is underway to expand DGPS coverage through a seven-agency partnership, for the Nationwide Differential GPS program. The data can be accessed for free and an accuracy of 1 to 10 m is normally possible using the transmitted corrections.

Subscription based correction methods, such as the OmniSTAR system or Starfire, use a network of reference stations to measure atmospheric interference inherent in the GPS system. Reference data are transmitted to global network control centers where it is checked for integrity and reliability. The data are then up-linked to geo-stationary satellites that distribute the data over their respective footprints. Using satellite re-broadcast overcomes the range limitations of ground-based transmissions. Additionally, these wide-area solutions correct for errors associated with a single reference station solution. The result is consistently high quality differential corrections available anywhere within the continental United States.

When GPS cannot be effectively used, alternate technology means of data positioning used on MEC projects are:

- Robotic Total Station (RTS)
- Ultrasonic Ranging and Data System (USRADS)
- Laser Fan
- Radio Frequency

RTS relies on positively positioning the total station and then servomotors are used to automatically search for and track the prism when operated in auto-mode. Using laser technology to plot azimuth and inclination, the total station logs the position of the prism in three dimensions (X, Y and Z) at the selected frequency. These positional data are combined with the geophysics data to provide positioning. RTS needs good line of sight between the total station and the prism but it will reacquire the prism if lost momentarily by a tree, for example.

USRADS relies on ultrasonic receivers located around the search area to receive transmissions from a transmitter attached to the geophysical sensor and then relay that information to a master receiver via radio wave where the position of the sensor is calculated based on the time it takes for the signal from the transmitter to reach each receiver. USRADS is also usable in tree cover but is slower to use because the receivers have to be moved from grid to grid to have good area coverage.

When overhead vegetative cover or other interference prevents the use of technology for positioning the data, line and fiducial marks on the ground are used. The EM 61, for example, can be set to automatically insert fiducial marks into the data with each revolution of the wheel when collecting data by pulling the sensor along the ground. Marks can be physically entered by the instrument operator based on pre-measured marks placed on the ground in each survey grid. When the data are processed, the sensor readings are interpolated (equally spaced) between the fiducial marks. Fiducial positioning is extremely sensitive to the speed at which the survey is conducted and relies heavily on the operator maintaining a consistent speed across the ground for the duration of each search lane and then, from lane to lane.

Table 4-2 provides some general information on technologies which may be used for positioning during DGM. The USRADS, Radio Frequency and Laser Fan systems are limited in supply and are not used very often on MR projects

Table 4-2. Example Analysis of Positioning Technologies

TECHNOLOGY	EFFECTIVENESS	IMPLEMENTABILITY	COST	REPRESENTATIVE SYSTEM	ADDITIONAL INFORMATION
DGPS	High: Is very effective in open areas for both digital mapping and reacquiring anomalies. Is very accurate when differentially corrected. Low effectiveness in wooded areas or near large buildings.	High: Easy to operate and set up. Requires trained operators. Is available from a number of vendors.	Low: Systems available for $100-$200 per day	Leica GPS 1200 Trimble Model 5800 Thales Ashtech Series 6500	Open area system
Robotic Total Station (RTS)	Medium: Is very effective in open areas for both digital mapping and reacquiring anomalies. Is effective near buildings and sparse trees. Commonly achieves accuracy to a few centimeters.	Medium: Easy to operate. Requires existing control.	Low: System is available for $150-200 per day.	Leica TRS 1100 Trimble Model 5600	Is recommended near houses or in open areas that have a high tree line.
Laser Fan	High: Is very effective in wooded areas. Can be used in open areas, though is limited due to range of transmitters. It is extremely accurate positioning system. Commonly achieves accuracy to a few centimeters.	Low: Technology has a time-consuming setup due to numerous parts and connections. Equipment is not ruggedized.	Low: System is available for less than $200 per day.	ArcSecond “In-door GPS” (Constellation)	Is recommended in wooded areas.
Radio Frequency	Medium-High: Can effectively survey open, vegetated, or cluttered areas with varying degrees of position accuracy. Can be set up over a 5-acre area.	Medium: Technique has not been successfully demonstrated on numerous MEC projects.	Medium-High: Purchase price is estimated to be $20,000- 30,000.	Ensco	There is only one manufacturer and limited supply at this time.
Acoustic	Medium-Low: Is not very efficient in open areas due to substantial calibration setup time. Is reasonably effective in wooded areas, although less accurate than other methods. Commonly achieves accuracy of 10-30 cm.	Low: This technology is difficult to set up, and there is minimal available support. Is negatively affected by certain aspects of environment.	Medium: System is available for around $200 per day.	Ultrasonic Ranging and Data System (USRADS)	Has been used extensively in wooded areas with success.

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4.2.4 Geophysical System Verification

Over many years, numerous geophysical prove outs (GPOs) have been performed on a variety of site conditions, and a significant body of knowledge has accumulated documenting the performance of these technologies. This accumulated understanding, along with the recognition that magnetic and EM responses of munitions may be predicted reliably using physical models, presented the opportunity for both streamlining and enhancing the GPO with a more rigorous physics-based approach. Using the GSV process, the resources traditionally devoted to a GPO are reallocated to support simplified, but more rigorous, verification that a geophysical system is operating properly, as well as ongoing monitoring of production work. The GSV is now the preferred geophysical validation process at Navy MRSs and the GPO is no longer used. The IVS consists of a reasonable number of objects in a line with the locations of the objects known to the sensor operator. In principle, the objects used in

the IVS can consist of any well-characterized object (i.e., a "surrogate item"). However, Industry Standard Objects (ISOs), similar in size and shape to common munitions, are recommended because sensor production curves are available for these objects. A single item in the IVS could be sufficient to generate instrument performance data (i.e., to ensure that the sensor system is recording the expected signal from a known object at the correct location). Usually, multiple items (3-7) are used to provide a range of signals.

Table 4-3 provides summary information for several typical ISOs used during a GSV. ISOs are typically standard size steel pipe nipples. The small ISO is roughly the size of a 37-mm projectile, the medium size ISO is comparable to a 60-mm mortar, and the large ISO is roughly comparable to a larger munitions item such as a 105-mm projectile or 4.2-inch mortar. The ISO for a 20-mm projectile is a bolt that approximates the size of the 20-mm. These ISOs will produce geophysical signals that are similar to those of the corresponding munitions items. Note that the ISOs in Table 4-3 are schedule 40 and that the small ISOs used for the advanced munitions classification are schedule 80. ISOs have advantages over munition surrogates in that the can be purchased at hardware stores and if lost, their appearance should not trigger an explosives safety concern of a munition item.

In addition, sensor response curves for common munitions have been published by the Naval Research Laboratory (NRL) in the following reports and a reference for the GSV process and software includes:

- *Geophysical System Verification (GSV): A Physics-Based Alternative to Geophysical Prove-Outs for Munitions Response* Addendum (ESTCP, September 2015)[30]
- *EM61-MK2 Response of Standard Munitions Items* (NRL/MR/6110-08-9155)[31]
- *EM61-MK2 Response of Three Munitions Surrogates* (NRL/MR/6110-09-9183)[32]
- *Geophysical System Verification Response Calculator* (ESTCP, February, 2010)

During the GSV, the IVS is well marked to ensure the sensor passes directly over the objects and that a peak signal is acquired. The distance between items in the IVS should be sufficient so that the sensor signal level returns to the noise level between the test strip items. Also during the GSV, a noise strip is surveyed. The noise strip is established sufficiently far from the IVS and is intended to allow a daily check of background conditions in an area representative of general site characteristics. The noise strips are typically run twice per day and should contain no discrete anomalies or non-representative terrain or geology that will affect the instrument response. Figures 4-5 show IVS data repeatability and reproducibility. Figure 4-6 shows an in-field inversion QC check on position with a MetalMapper 2x2. Figure 4-7 is an example deliverable for an AGC sensor on initial static IVS seed position accuracy.

Table 4-3. Common ISOs Used for Geophysical Verification

ITEM	NOMINAL PIPE SIZE (Standard DGM/AGC)	OUTSIDE DIAMETER	LENGTH	PART NUMBER(1) (Standard DGM/AGC)	ASTM SPECIFICATION
20-mm ISO	Bolt	5/8"-11 Thread	2 inch (50.8 mm)	91571A266	A325
Small ISO	1″ Sch 40/80	1.315 inch (33 mm)	4 inch (102 mm)	44615K466/4550K226	A53/A773
Medium ISO	2″ Sch 40	2.375 inch (60 mm)	8 inch (204mm)	44615K529	A53/A773
Large ISO	4″ Sch 40	4.500 inch (115mm)	12 inch (306 mm)	44615K134	A53/A773

(1) Part number from the McMaster-Carr catalog.

A production blind seeding program is required to verify system performance during geophysical surveying. During a blind seeding program, objects similar to those that would be installed in the IVS are buried in locations that are not known to the geophysical equipment operator or data analyst. As with the IVS, ISOs are recommended. ISOs do not resemble munitions items but provide similar geophysical response. This avoids potential issues with surrogates and recovery of a munitions item (even if inert) by someone outside the project. Additionally, ISOs are readily available and inexpensive.

Typically, at least one seed should be encountered per day per crew. For a field crew using a cart-based EM-61, the production rate might be one acre per day. One seed per acre would be appropriate in this case. For analog systems, the number of seeds per person is much higher due to the limitations discussed in section 4.2.1. More information on seeding rates for the different sensors is provided in the Munitions Response QAPP Toolkit Module 1: RI/FS, December 2018 [24].

Blind seeding is a powerful process monitoring tool that can serve to increase regulator and stakeholder confidence to a high enough level that post-remediation QC activities such as

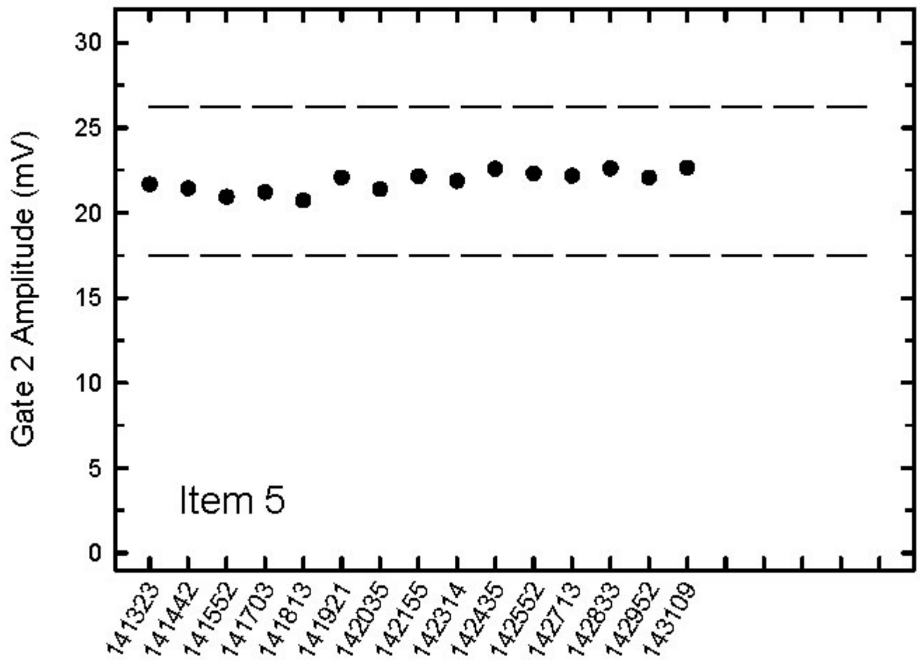


Figure 4-5. Example Deliverable
Cumulative Plot of ISO Amplitudes Showing Failure Criteria Limits for EM 61

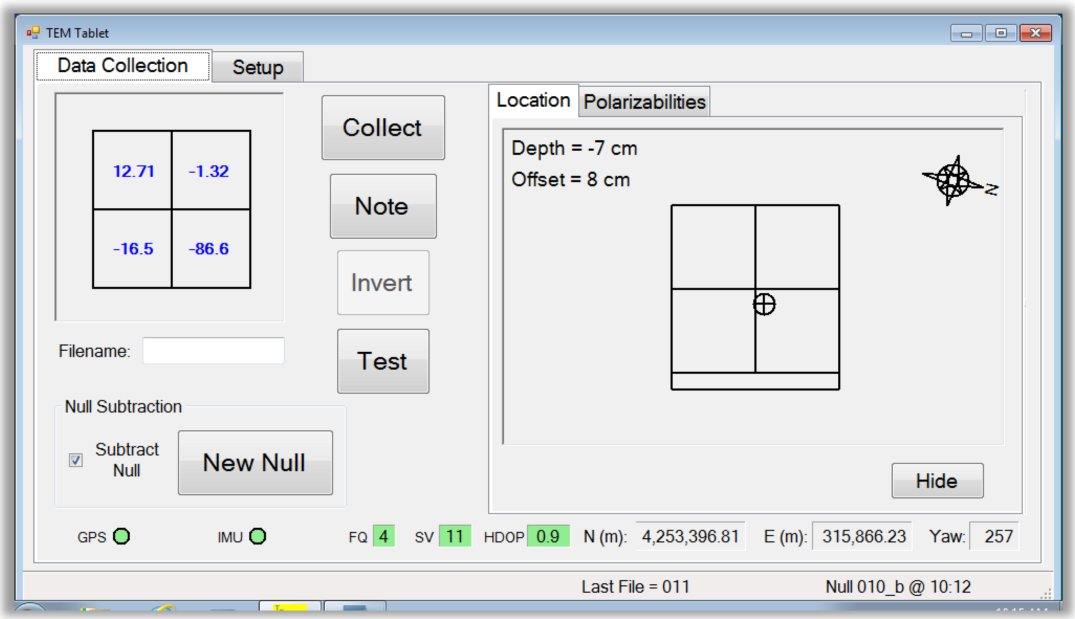


Figure 4-6. Quality Control In-field Inversion Check of Position for MetalMapper 2x2

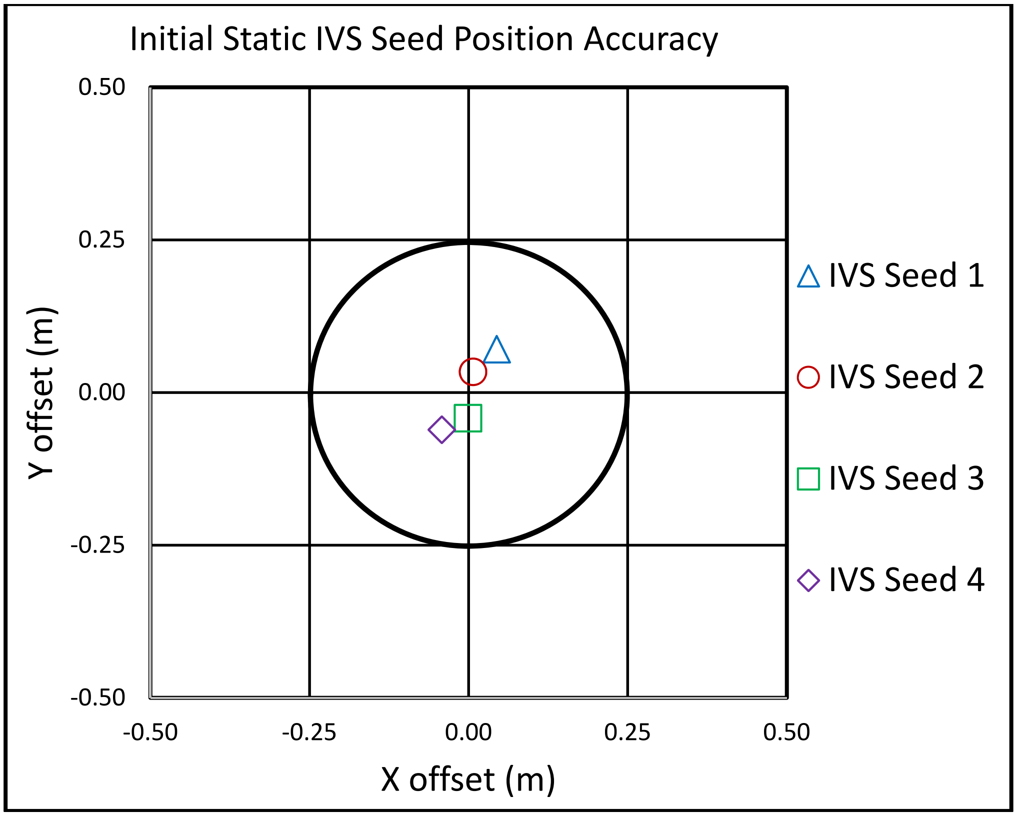


Figure 4-7. Example Deliverable AGC
Evaluation of Initial Static IVS Seed Position Accuracy

verification sampling may not be necessary. Blind seeding tests and validates the geophysical detection process and provides ongoing verification that known objects produce signals that are to be expected. If the geophysical survey team detects and measures the correct responses from the blind seeds, it is assumed that the geophysical procedures are working as planned. If, on the other hand, the geophysical survey team fails to find a blind seed, this indicates that the detection process may not be adequate or the survey team is not implementing the detection process adequately.

For either an IVS or a blind seeding program, if ISOs are used, instrument response can be effectively correlated to system performance to make conclusions regarding program QC. If a surrogate item is used for which there is no expected repeatable response, then only a detect vs. non-detect determination can be made, which lessens the power of the verification survey.

4.3 Data Processing, Analysis and Anomaly Selection

4.3.1 <u>Basic Data Processing</u>

Data which are logged during DGM must be post-processed so that they can be analyzed and interpreted. The basic processing steps involve merging the positioning data with the sensor data into a basic X, Y, Z1, Z2, etc. file. There are techniques applied to level the data (essentially achieving a standard baseline reading for the data from which to begin) and for adjusting the data for latency (the time between when the data are taken and the position can be recorded) and other basic data management tasks. Many of these tasks have been automated in software applications designed specifically for UXO detection. The X, Y, Z file is then gridded and plotted according to X, Y coordinates and the Z value(s) assigned a color to represent the three dimension (amplitude). The product is a colored contour map showing the variation in amplitudes on the site. The data are also presented in profile (side view) showing the peaks and valleys of the individual anomalies with their respective amplitude values. Some software has an automatic 'peak-picking' algorithm which automatically selects anomalies whose peak value is above a pre-set threshold. The coordinate positions and amplitudes for these anomalies are pulled from the data and these become the target list for reacquisition. Data processing is performed by a geologist or geophysicist.

Computer and analytical software systems are available to assist with processing geophysical survey data, producing maps demonstrating the data, and interpreting the data to determine if anomalies exist that warrant further investigation/excavation. One example of an analytical software package available to assist in interpreting geophysical survey data is Oasis Montaj from Geosoft. This program is capable of processing and interpreting geophysical survey data, providing QC checks on the data, and producing geospatially-referenced maps. The program contains a UX-Process Module, which is a platform for geophysical data correction and interpretation, containing tools for QA/QC, target analysis, survey planning, and progress monitoring. The program also contains a UX-Analyze Module that can perform data analysis, modeling, and target classification and selection for the advanced classification capable sensors and is discussed in section 4.4.

4.4 Advanced Classification Technologies

Even with robust interpretation of geophysical survey data to identify anomalies warranting further action, cleanup costs at an MRS are typically dominated by excavating non-munitions items. In fact, often less than 5% of items targeted for reacquisition and excavation typically are confirmed to be MEC.

Figure 4-8 demonstrates the typical distribution of costs for a MRS investigation and response action. Clearly, significant cost (and time) savings could be realized if successful classification between munitions and other sources of anomalies could be implemented.

Munitions response geophysical classification is the process of using geophysical data to make a decision as to whether a buried metal item is potentially hazardous (i.e. MEC) or not. High-quality geophysical data can be interpreted with physics-based models to estimate parameters that are related to the physical attributes of the object that resulted in the signal, such as its physical size and aspect ratio. The values of these parameters may then be used to estimate the likelihood that the signal arose from an item of interest, that is, a munition. EMI data are typically fit to a three-axis polarizability model that can yield parameters that relate to the physical size of the

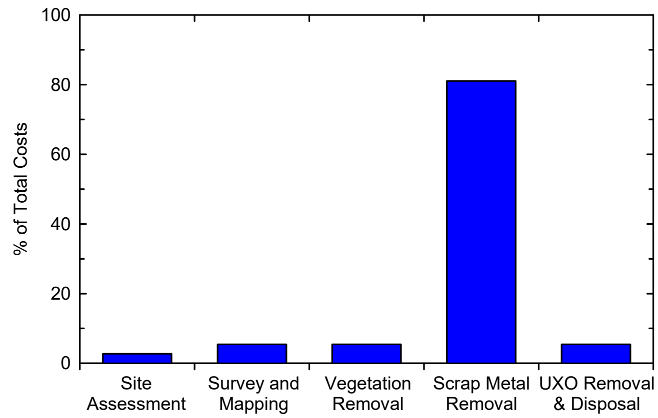


Figure 4-8. Typical Cost Distribution for a MRS Response Action

object, its aspect ratio, the wall thickness, and the material properties. The physics governing the electromagnetic response of a metal object is well understood and predictable. Data collected with these sensors contain the same information content on any site and demonstrations to date have confirmed that classification works predictably.

Munitions are typically long, narrow cylindrical shapes that are made of heavy-walled steel. Common clutter objects can derive from military uses and include exploded parts of targets, such as vehicles, as well as munitions fragments, fins, base plates, nose cones and other munitions parts. Other common clutter objects are man-made nonmilitary items. While the types of objects that can possibly be encountered are nearly limitless, common items include barbed wire, horseshoes, nails, hand tools, and rebar. These objects and geology give rise to signals that will differ from munitions in the parameter values that are estimated from geophysical sensor data.

Once the parameters are estimated, a methodology must be found to sort the signals to identify items of interest, in this case munitions, from the clutter. This is called *classification*. In a simple situation, sorting items could be based on a single parameter, such as object size. A rule could be made that all objects with an estimated size larger than some value will be treated as potentially munitions items of interest, such as large bombs, and those smaller could not possibly correspond to intact munitions.

In reality, many classification problems cannot be handled successfully based on a single parameter. Because the parameter-estimation process is imperfect and the physical sizes of the objects of interest may overlap with the sizes of the clutter objects, it is rare to get perfect separation based on one parameter. For complex problems, sophisticated classifiers can combine the information from multiple parameters to make an estimate of the relative likelihood that a signal corresponds to an item of interest.

There are websites that can provide more information on AGC. The ESTCP website, www.serdp-estcp.org maintains the AGC project reports and guidance. The document "Implementing Advanced Classification on MRS: A Guide to Informed Decision Making for Project Managers, Regulators, and Contractors" [33] is useful as well as the latest ESTCP demonstrations reports and the FAQs. ITRC also has guidance documents on its website that are useful, www.itrcweb.org. The AGC QAPP template is posted on the Denix website, www.denix.osd.mil. The information presented in this document is derived from these resources and is expected to be current as of the time of this document. However, clearly it will be subject to change as advancements are made.

4.4.1 AGC Sensors

Digital geophysical data are required for classification. Most successful classification applications have been based on EMI data. In principle, magnetometer data can be used, but magnetometers inherently provide less information about the target being interrogated and are more susceptible to geologic interference. Both of these factors limit what is achievable with magnetometer data. This section will focus on EMI, and the discussion will be in terms of time domain systems, which are most common.

In very, very rare, relatively simple MRSs (only one large munition used at the site), some rudimentary classification (reduction of scrap by about 50%) can be achieved with standard, commercial (i.e., EM61-MK2) sensors. As a general rule, these sensors do not collect enough high quality data to perform satisfactory classification at the type of MRS a typical RPM will manage. At more typical MRSs the RPM will manage, the best classification results have been achieved using advanced sensors and interpretation techniques to reduce the amount of scrap by 75 to 90+%.

Most EMI sensors in the time domain transmit a pulsed electromagnetic field and sense the responses of nearby objects once the field has been turned off. Figure 4-9 shows a schematic of two cycles of this process that can be repeated as many times as is required for signal fidelity.

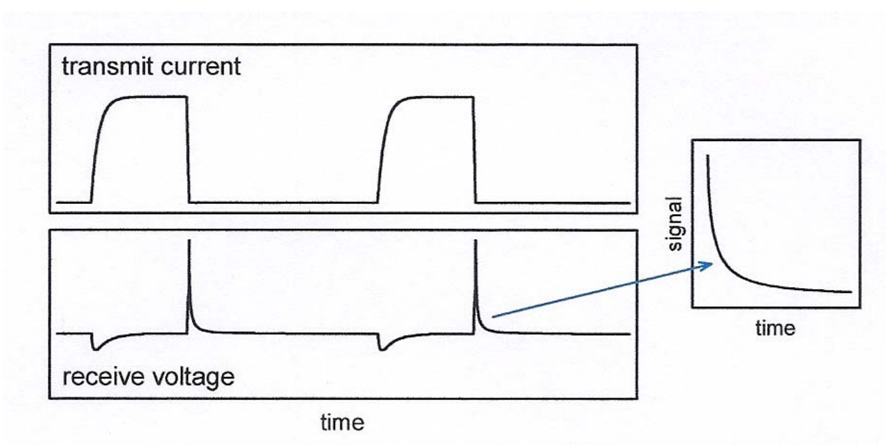


Figure 4-9. Schematic of the Time-domain EMI Process
(Current is pulsed through a transmit coil which results in a pulsed electromagnetic field under the sensor. While on, this field magnetizes the metal target and when rapidly turned off, excites eddy currents in the target which are sensed by a receive coil. The amplitude and decay properties of these currents are used in classification.)

For classification, one important aspect of EMI is illuminating the target from multiple directions and sensing the return field in multiple directions. This allows the sensor to completely sample the target response in three dimensions. A second important parameter is when in time the signal is sampled after the transmitter is turned off. The decay of this signal is related to the wall thickness of the object and its material properties, which are important features for classification, and the longer the decay is sampled, the better this decay can be determined. The received signal is also dependent on the distance and relative orientation of the object and the sensor, as well as the properties of the receivers.

AGC sensors that are purpose-built to support munitions classification differ from standard commercial sensors (i.e. EM61-MK2)) in two important aspects: they sample multiple axes at a single point in space and they are able to sample the time decay in finer steps that go out much longer in time. The longer sample times and finer steps are illustrated in Figure 4-10. Figure 4-11 illustrates the difference between dynamic data and cued data collection for an AGC sensor.

Commercially Available AGC Sensors
ESTCP has performed pilot tests with a number of advanced sensors capable of performing classification. Three systems developed under that program are now available for purchase. Two systems on smaller platforms intended for use in more restrictive terrain and vegetation include the Person Portable Vector Sensor (PPV), and the MetalMapper 2x2. Compromises in size, transmit moment, and other features compared to their larger counterparts have some impact on their capabilities, particularly the depths to which targets can be detected and classified, but they provide advanced capability in environments not currently accessible. The MetalMapper is mounted on a large sled or cart platform and can be deployed in terrain where such systems can be maneuvered. Descriptions of each these sensors are provided in this section.

MetalMapper: The MetalMapper, developed by Geometrics, is available for commercial use [34]. It is designed to be a stand-alone survey and cued detection system. The system is composed of three orthogonal 1-m × 1-m transmitters for target illumination and seven three-axis receivers for recording the response. Its sampling is programmable, and therefore flexible. In demonstrations to date, it has measured the decay curve up to 8 ms after the transmitters were turned off. It has been used in a sled or a wheeled configuration mounted to a front loader tractor or utility vehicle. Centimeter-level GPS is used for navigation and geolocation and an inertial measurement unit (IMU) is used to measure platform orientation [35]. Figure 4-12 shows a MetalMapper sensor.

In survey mode, only the vertical field transmitter is used and the receive data recording is truncated on the order of 1 ms after the turnoff of the transmitter. In cued mode, MetalMapper is positioned over each anomaly on its target list and collects the full suite of data while stationary.

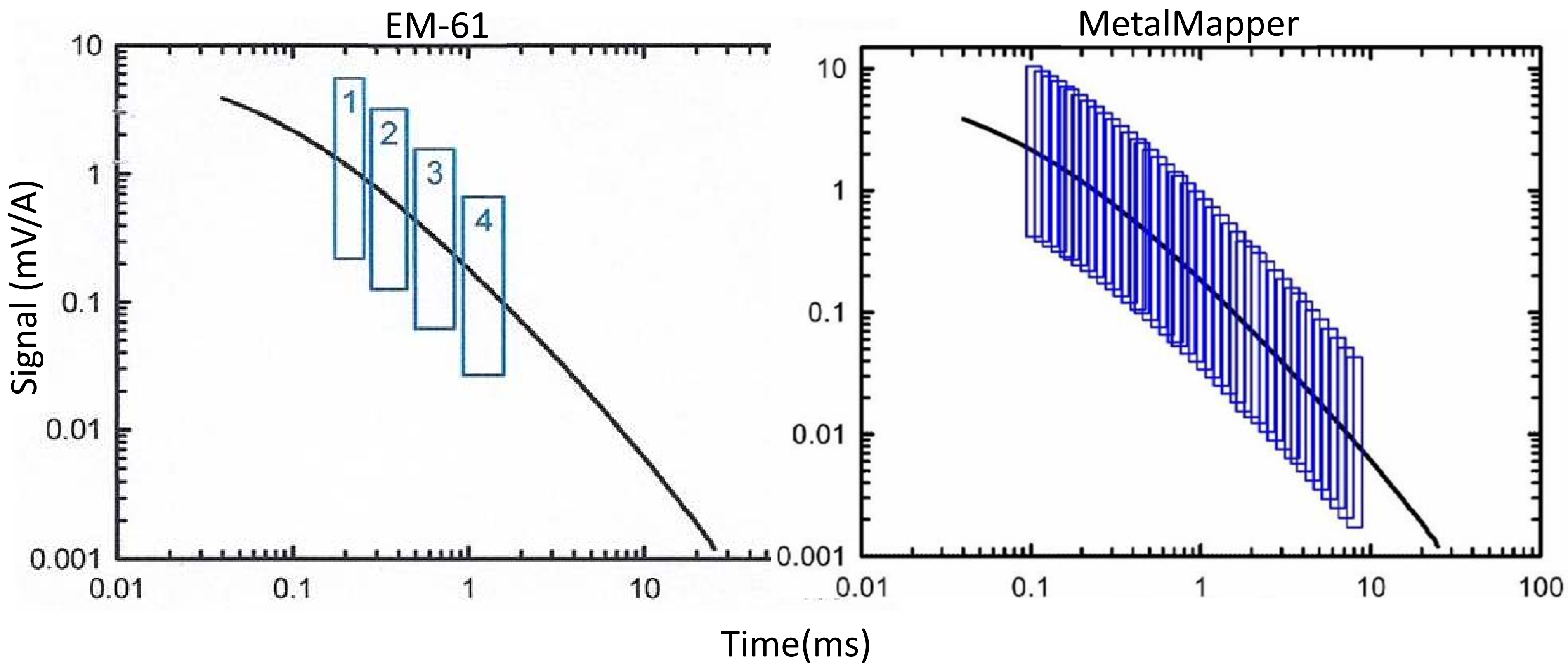


Figure 4-10. Comparison of Time Gates in which the EM-61 and MetalMapper Samples the Decaying Response of the Target (The black curve is the response of a metal target.)

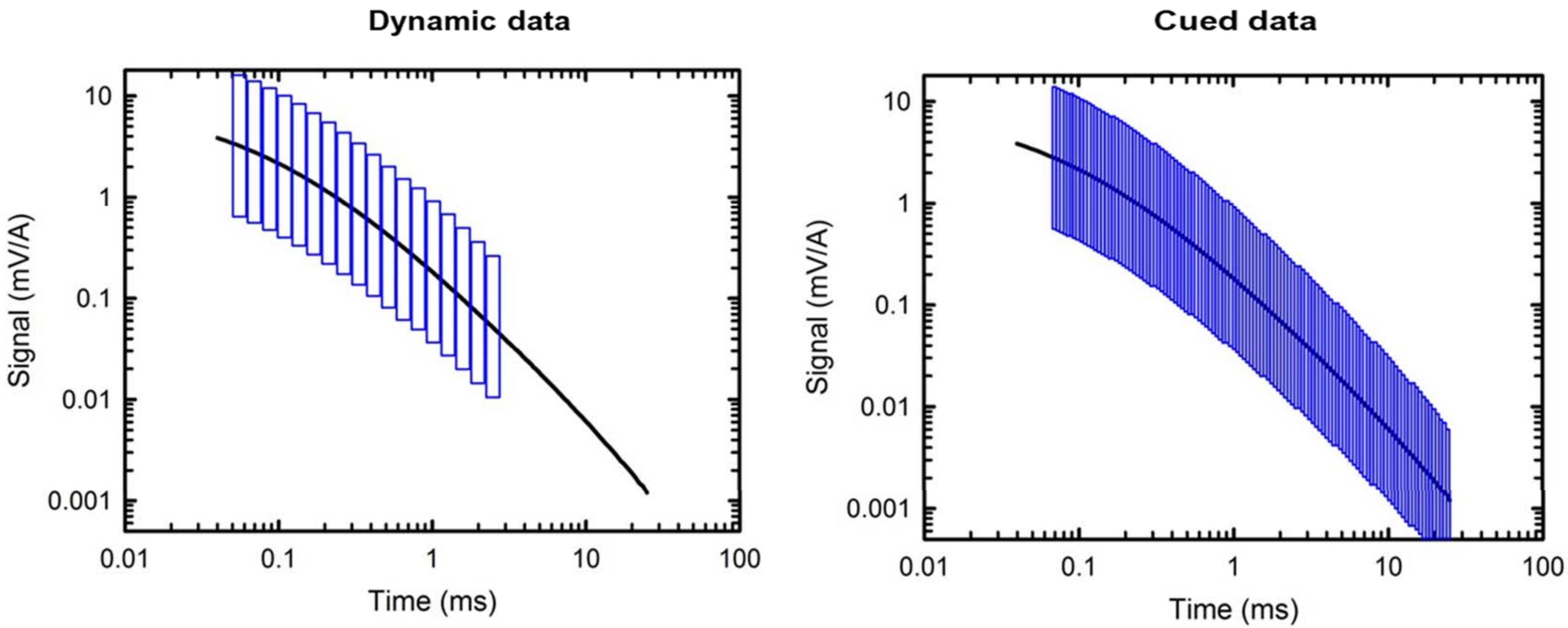


Figure 4-11. Comparison Dynamic and Cued Modes of MetalMapper 2x2 AGC Sensor

(Dynamic data has wider time gates and a shorter time for measurement(~3ms) as opposed to cued data which has narrower time gates and longer time for measurement (~25ms). The black curve is the response of a metal target.

MPV: The MPV is a time-domain, EMI sensor composed of a single transmitter coil and an array of five receiver units that measure all three components of the EM field [36]. The MPV sensor head is comprised a 50-centimeter (cm) diameter circular loop transmitter coiled around a disk that intermittently illuminates the subsurface, and five 8-cm multi-component receiver units (cubes) that measure the three orthogonal components of the transient secondary EM field decay.

Cued data are collected in a 9-point grid around the flagged anomaly location using the MPV beacon positioning system to obtain local sensor positions. The positioning system works by locating the origin of the primary field generated by the MPV transmitter coil, acting as a beacon, with a pair of EMI receivers rigidly attached to a portable beam, placed horizontally on the ground and supported by a pair of tripods to act as a base station. The azimuth of the MPV and boom are recorded with a 3-component attitude sensor. Decay data are collected to 25 ms after

Figure 4-12. MetalMapper

primary field turn-off for this survey. The analytical software that processes the data is not part Oasis Montaj UX-Analyze at this point in time. Figure 4-13 shows the smaller, more portable versions of AGC sensors.

MetalMapper 2x2: The MetalMapper 2x2 array comprises four individual EMI transmitters with 3-axis receivers, arranged in a 2 x 2 array[37]. The center-to-center distance is 40 cm, yielding an 80 cm x 80 cm array. The data acquisition computer is mounted on a backpack worn by one of the data acquisition operators. The second operator controls the data collection using a personal data assistant (PDA) which wirelessly communicates with the data acquisition computer. The second operator also manages field notes and team orienteering functions.

For each series of measurements with the array, the four transmitters are energized sequentially. After each excitation pulse, the response of all twelve receive coils is recorded, resulting in 48 (4x4x3) transmit/receive pairs. Data are recorded for 25 ms after transmitter turn-off.

Figure 4-13. Smaller, more portable versions of AGC sensors: MPV (left) and MetalMapper2X2 (right)

Table 4-4 provides a summary of the features of all the advanced sensors above, as well as the conditions where their implementation is expected to be successful.

Table 4-4. Summary of Advanced EMI Sensors Tested by ESTCP

SENSOR	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY
MetalMapper	1-meter cube Three-axis transmit Seven three-axis 10-cm receive cubes Continuous sample to 8 ms after turnoff	Near-perfect Classification demonstrated in live sites Good depth – large transmit moment	Survey and Cued Requires vehicle to maneuver Requires GPS
MPV	Hand carried on a wand, 12 pounds 50-cm diameter transmitter one dimension only Five three-axis 8-cm receiver cubes Continuous sample to 25 ms after turnoff Can be manipulated in 3D to get multiple views of the target	Good classification on test site results Will have less depth capability because of smaller transmit moment	Detection and cued modes Small and maneuverable for applications in wooded areas Does not require GPS to operate Uses locating beacon Higher than optimal weight when compared to traditional handheld sensors Processing software is unique
MetalMapper 2X2	Transported on a small cart, 4 pounds. Overall dimension 80 cm square. Backpack 25 pounds Four 35-cm transmitters 8-cm, three-axis receive coils centered in each Continuous sample to 25 ms after turnoff	Good classification on test site First live site demonstration in summer 2011 Less depth capability because of smaller transmit moment	Detection and cued modes Does not require GPS Fully samples target response from a single location

Other Sensors

Any new system should have proposed methods and procedures that can be independently demonstrated in blind tests as a part of the pilot testing. RPMs should consult with your Munitions Response Workgroup member about any new technology proposed for a site.

4.4.2 Data Collection Modes

Classification data may be collected using cued or dynamic modes. A cued survey is a stationary data collection over a previously-identified anomaly for the purpose of acquiring higher-quality data to use for classification. Cued surveys only make sense using an advanced EMI sensor; not enough information is available in a single-coil, single-axis sensor such as the EM61-MK2 to make cued data collection worthwhile.

Geophysical data collected in the cued mode can be much more abundant because of the additional information collected as the sensor resides over the anomaly longer as compared to dynamic collection. The obvious disadvantage of collecting cued data is the lesser area covered per unit of time. However, the higher resolution/more abundant data usually leads to more definitive classification without the need to collect additional geophysical data for some anomalies relative to a dynamic survey. While site and specific sensor platform dependent, it is typical to be able to collected cued data for 150-200 anomalies per day.

When performing data collection in dynamic mode, the sensor is moved continuously over the survey area, which is similar to standard DGM detection survey where the goal is to cover 100% of the investigation area or as much as is practicable. A dynamic survey is often accomplished using back and forth parallel survey tracks (akin to mowing the grass) with the track spacing a function of the sensor width, smallest munition to be detected, and anomaly density. The data from the geophysical sensor are combined with geolocation data (usually GPS data but other geolocation systems are used under tree cover) and mapped. Detections are declared at the locations of anomalous geophysical response compared to background. Use of an advanced sensor for the detection survey allows for more sophisticated data analyses such as Informed Source Selection.

An advantage to the use of AGC in a dynamic survey is the precise position and orientation sensors on the advanced systems results in much better location of the observed anomalies – often within 15 to 20 cm as opposed to 50 to 75 cm with traditional sensors. The second advantage is the ability to perform much more sophisticated anomaly selection (e.g. Informed Source Selection) when working with data from the advanced sensors. The additional information provided by the advanced EMI sensors affords the analyst the opportunity to use more than the observed signal amplitude to select only those anomalies that could result from a target of interest (TOI) for further consideration.

At present, the disadvantage to the use of advanced sensors for detection surveys is the production rate. The limited size and inability to configure them as arrays limits the daily survey coverage to 0.75 to 1.5 acres. On small sites this is not an issue but on larger, open sites, it is common to make an array of EM61s and survey up to 5 acres per day.

Depending on site conditions, this limited survey coverage can be offset by the reduction in the number of anomalies that required cueing. On a site with moderately high anomaly density (1000 anomalies per acre or above) mostly consisting of small clutter, Informed Source Selection can reduce the number of cued measurements by up to a factor of three. On sites with low anomaly densities such as buffer areas, the limited number of anomalies does not afford enough reduction in cued data collection effort to offset the lower survey rates of the advanced sensors.

4.4.3 Data Processing Using Models

There are important reasons that models are used instead of the data directly acquired from the advanced sensors. The data, as measured, reflect a complex interaction of the sensor and the target. Direct data features, such as the amplitude and the shape of the anomaly, are a result of not only the intrinsic target features, but also the sensor characteristics and the relative orientation of the sensor and target. The same target measured from a different distance or orientation will exhibit different signal amplitude and decay. This clouds the interpretation of direct data features.

In order to interpret the data, models of the EM response of the munitions are used. The models use the physical properties of an object to predict the signal it will produce in a sensor. For EMI, the simplest and most common model is based on the dipole response of the object along three orthogonal axes. Figure 4-14 illustrates the three principal axes of a projectile and a fragment. A dipole consists of two equal and opposite point charges. It is the first term in a mathematical expression commonly used to describe electromagnetic fields. At distances large in comparison to the size of the object being modeled, the electromagnetic field depends almost entirely on the dipole moment. The dipole is an approximation of the total field that is simple enough to use for efficient analysis and, in most cases, captures the important features of the target. This model assumes a target can be described by orthogonal dipole responses oriented along the three principal axes of the target shown in Figure 4-14. The model uses the characteristics of the transmitted signal of the sensor system being modeled to calculate the field that the object will experience and the resulting voltage measured at the sensor receive coil along the principal axes. The calculated responses reflect the size, shape, and material properties of the object (intrinsic features). The received signal is also dependent on the distance and relative orientation of the object and the sensor, as well as the properties of the receivers, which are captured in the model.

In the *inversion* process, the model parameter values are continuously adjusted until a solution is found that accurately reproduces the measured data. Inversion can be used to estimate the physically meaningful parameters that appear in the model, related to attributes such as size and shape. A measure of how closely the measured data are reproduced gives an indication of how confident one can be that the solution is meaningful.

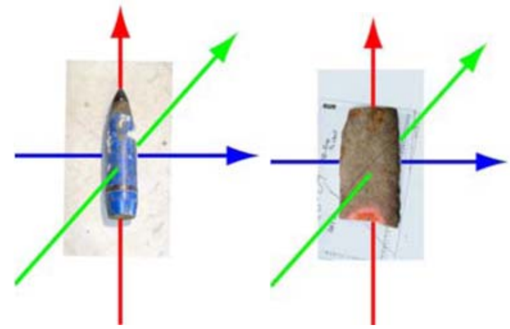


Figure 4-14. Three Principal Axes for a Projectile (left) and a Mortar Fragment (right)

Commonly, the object's response coefficients (munitions item modeled parameters), which are often referred to as polarizabilities, are represented as betas (βs). Long cylindrical objects, such as many munitions, will have one large and two small βs, corresponding to one long axis along the body and two shorter axes perpendicular

Figure 4-15 shows the difference in target response coefficients for a single 37mm projectile and a horseshoe. Since the horseshoe is flat but not quite symmetric, it has two large and one small response and the larger responses are similar but not identical. These differences between response coefficients are then used to classify an item.

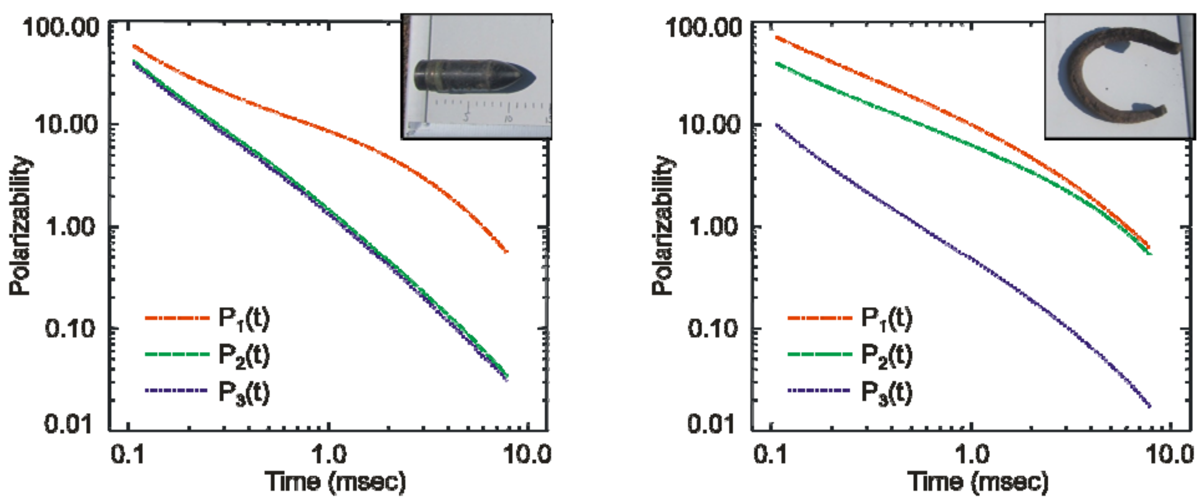


Figure 4-15. Target response coefficients (Polarizabilities) for a 37-mm Projectile and a horseshoe

Some common model parameters are listed in Table 4-5. The model separates the intrinsic (i.e. native features) from extrinsic features. Intrinsic features are more robust for making classification decisions on whether an item is a munition or not. Extrinsic features are useful for improving the digging process, where good estimates of location and depth can help assure that the correct target is reacquired and dug up. Inversion-based decay rates can be calculated from advanced sensor data. These analyses remove the effect of extrinsic properties such as distance and relative orientation to produce decay rates that reflect only the properties of the object. Table 4-6 shows the relationship between the polarizability properties and the target properties. The polarizabilities in Figure 4-15 can be thought of as "EMI fingerprints" of the object.

Table 4-5. Model Parameters

MODEL PARAMETERS	
EXTRINSIC	**INTRINSIC**
Location Orientation	Polarizabilities-relate to object size and aspect ratio Decay-relates to wall thickness and material properties

Table 4-6. Relationship of Polarizability and Target Properties

Polarizability Property	Target Property
Decay Rate of Polarizabilities	Wall Thickness
Relative Magnitude of Polarizabilities	Shape
Total Magnitude of Polarizabilities	Size (Volume)

Analyses are straightforward for isolated objects with strong signals that have been sufficiently illuminated by the sensor. As the noise level increases or as the target strength decreases, for example small or deep items, the analysis can become less reliable. Multiple objects having overlapping signatures are a known challenge.

Parameter extraction based on a dipole model is commercially available in the Geosoft software package Oasis Montaj as part of the UX-Analyze module. Models are available and documented for the MetalMapper, the MetalMapper 2x2, and the MPV.

4.4.3 Classifiers

Classifiers are computer algorithms that are used to determine the likelihood that a signal arises from a TOI like a munition. Parameters that are meaningful in distinguishing TOI from non-TOI are identified. In general, which parameters are meaningful will depend on the munitions of interest, the site conditions, the data quality, and other factors.

The parameters of munitions items are contained in a TOI library, which is a collection of responses (polarizability decay curves or EMI fingerprints) corresponding to commonly occurring munitions items. Most classification schemes involve comparing the EMI responses of the unknown objects to each entry in the library and using the match (or lack of match) to decide if the unknown is likely a munition or clutter.

ESTCP is compiling a master TOI library of munitions' responses along with complete metadata. This library will be maintained and updated as required by the USACE and hosted on a Government site. The current version of the library will be downloaded by the Government program manager at the start of the project and distributed to the geophysical contractor. For most projects, this will be the only library needed. Some sites may have unique munitions specific to the former mission and, in those cases, the master library will need to be supplemented with additional site-specific responses. Procedures for constructing these site-specific libraries will be described in the on-line help for UX-Analyze.

Figure 4-16 is an example two-dimensional plot that can be useful to visualize data and identify clusters of similar items. Ideally, the TOI will cluster in one area, that is, they will all look similar to one another in parameter space. In this case, the various size projectiles that make up the TOI form readily identifiable tight clusters, and all are concentrated in the area with larger sizes and longer decay times. In reality, this plot represents only two out of many dimensions that will ultimately be used to make a classification decision in the computer algorithm.

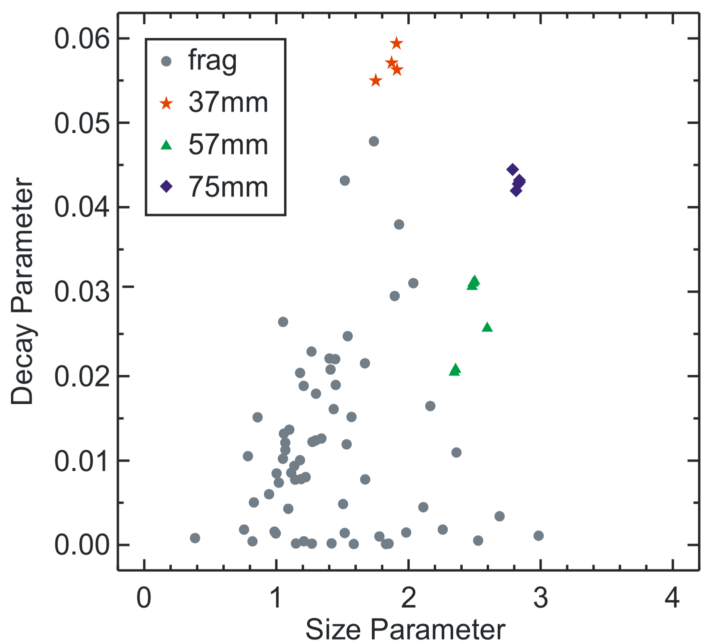


Figure 4-16. Simplified plot of a decay parameter versus a size parameter.

The classifier computer algorithm is then used to formulate a relationship to the likelihood that an item is a TOI. Some classifiers evaluate the parameter values directly and establish mathematical relationships to determine which combinations of feature values make an object look like a TOI. Classifiers rely on how well features match to a library of signatures. In this case, if an unknown object has a set of features that are similar to the features of a known item, then the unknown object can be matched to the library. This method can often lead to very high confidence in the library matches but risks misidentifying objects that are munitions but are types not included in the library. It is important to know what munitions items are expected from the site records and literature search and to compare this against the library munitions items in order to identify TOI that maybe difficult to correctly classify.

The ultimate product is a probability or metric that an item is a TOI. These likelihoods are relative and depend on many assumptions that go into building the classifier. They do not directly translate to commonly understood probabilities, such as a coin flip.

Most successful classification schemes in munitions have relied on a hybrid approach. First responses that match the items in the library can be classified as TOI with very high confidence. In addition, each response is examined individually to look for features such as size, symmetry and decay rate that make it look munitions-like and these objects are also labeled as TOI.

Classifiers may require some amount of "training." The objective of training is to teach the classifier what the TOI on the site looks like. This is typically accomplished by providing the truth data for a fraction of the excavated items. This may be 100% truth for a small portion of the site. In most cases, targeted training data may be requested to explore the origins of signals with particular features. It is also possible to derive training data from historical archived work.

The classifier does not draw a line between the TOI and non TOI. The end product is a ranked anomaly list within which a threshold must be specified. In many cases, hybrid methods are used to both match to a library and to look for munitions-like objects. It is more properly thought of as a merging of multiple ranked anomaly lists corresponding to the various criteria that define TOI. At this point the analyst must decide where to draw a threshold. This decision is informed by "training data" on a small number of anomalies for which the analyst requests the identities.

4.4.4 Ranked Anomaly List and Stopping Point

The final process is to develop an anomaly list ranking all of the detected anomalies by the likelihood that they are TOIs. Figure 4-17 shows a sample ranked anomaly list.

Once the anomaly list is constructed, at a minimum, all of the anomalies in the red part of the list, those identified as high confidence TOI, would be dug, as would all of those in the can't analyze category. Once the threshold between TOI and non-TOI is determined an additional 200 anomalies (sequential below the threshold) are dug as the "threshold verification". Validation excavations are also conducted, which consists of digging 200 randomly selected anomalies remaining below the threshold following the anomalies dug for verification. The verification digs are conducted to insure that the appropriate TOI/non-TOI threshold was identified. The validation digs, in addition to the successful detection and classification of blind seeds, shows that the features that were the basis for the decision on each item were correct.

The Data Usability Assessment (DUA) is performed by key members of the project team at the conclusion of data collection activities for each phase of investigation (i.e., the detection survey, the cued survey, and the intrusive investigation) before proceeding to the next phase. The DUA uses the outputs from data verification and data validation (e.g., blind seed results, verification digs, validation digs), including the Final Classification Validation Report.

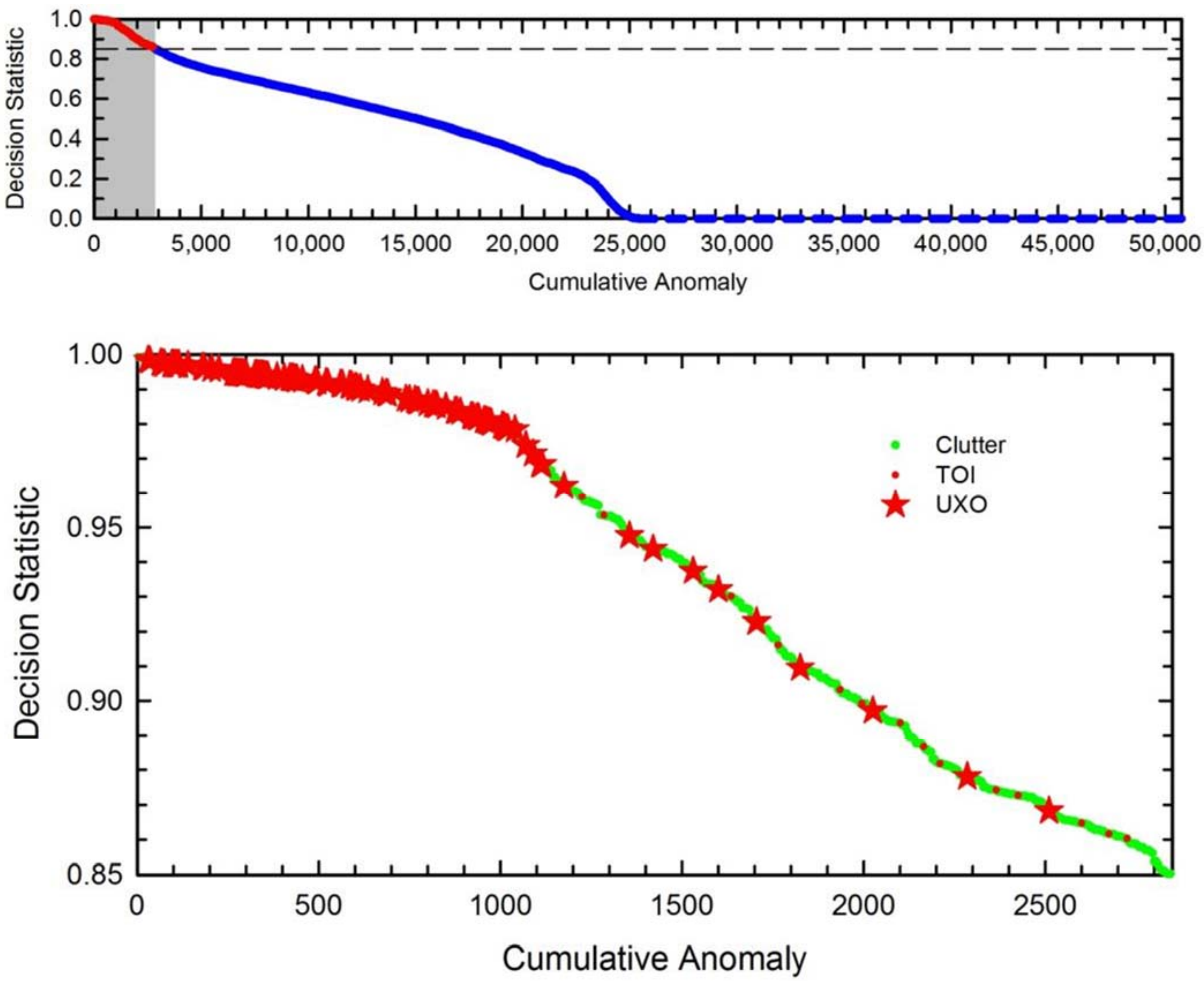


Figure 4-17. Ranked Anomaly List for Classification

The different phases of the DUA involves a qualitative and quantitative evaluation of environmental data for the detection phase, cued phase, and intrusive investigation, to determine if the project data are of the right type, quality, and quantity to support the MPCs and DQOs specific to that phase of the investigation. It involves a retrospective review of the systematic planning process to evaluate whether underlying assumptions are supported, sources of uncertainty have been managed appropriately, data are representative of the population of interest, and the results can be used as intended with an acceptable level of confidence.

4.5 Quality Considerations

During the RI activities, all data should be carefully evaluated to ensure that project objectives have been met. If quantitative DQOs have been identified, then the generated data must be compared to those DQOs. Regulators and other project stakeholders should also perform a review of the project data to ensure data quality and that project objectives have been met. The overall dataset from the RI should be assessed to determine the need for a remedial action at the MRS. The purpose of the RI is not to remove all site uncertainty, but to fill the data needs for determining risk/hazard and developing and comparing remedial alternatives.

For MEC RI/FS QAPPs, the Munitions Response QAPP Toolkit Module 1: RI/FS, December 2018 [24] is normally the best example to start development of the site specific MEC QAPP for RI/FS work.

The RPM has overall responsibility for project oversight but may rely heavily on technical support from RTMs, Navy Technical Representatives, Facilities Engineering & Acquisition Division/Resident Officer in Charge of Construction field engineers and others. The RPM should hold weekly conference calls with the contractor and others, as needed, to discuss field operations and quality when field work is being performed.

The production contractor is responsible for QC which includes:

- QC inspections on each DFW (three phases of control: preparatory, initial, and follow-on);
- Install and manage the IVS. Install and account for all QC blind seeds;
- QC of completed work including final inspection of any grids; and
- Initiation of deficiency notices for deficient work or field change requests to adjust field procedures for changes in site conditions.

Per the Office of the Assistant Secretary of Defense memorandum dated April 11, 2016, all contractors performing AGC must meet the requirements and be accredited through the DoD Advanced Geophysical Classification Accreditation Program (DAGCAP).

Third-party QA may be conducted NAVFAC, NSWC IHEODTD, or by an independent third party contractor. NOSSA will audit selected MRSs to assess the extent to which the project complies with applicable environmental, safety, and occupational health requirements related to the management of MEC/MPPEH. Sites selected to be audited will be at the discretion of NOSSA. Those sites that are transferring out of Navy control will be the highest priority.

To ensure quality in the initial survey to detect buried metallic items at the site, verify that all equipment checks and geophysical sensor warm-up procedures were performed satisfactorily. The project geophysicist documents these and other quality checks with standardized forms. Equipment check forms include verification of daily static checks within the required metrics (typically +/- 10% of the expected values for the time gates). Another standard to ensure quality in the initial survey is the measurement of consistent peak signal results from the twice-daily IVS survey. The surveys should also detect all blind seeds in the mini/full-coverage grids and place them on the list for interrogation.

For standard DGM the data (location and amplitude) need to be compared against the intrusive investigation results for reasonableness and accuracy. Circumstances such as high amplitude targets, which are identified as very small objects or as geologic in nature, should be investigated.

Depths of recovery for items should be compared against the anomaly amplitude for reasonableness (e.g., very low amplitude target reported at a very deep depth). These types of misreporting can severely impact the cost for the follow-on remedial action by forcing the project team to set the anomaly picking threshold for the RA at an unreasonably low amplitude. This drives up the number of targets which must be investigated.

If any data gaps are identified, they should be documented and explained. Additional action may be required as part of a follow-on investigation or as part of the ultimate response action to correct any deficiencies.

Quality on a MRS project using geophysical classification is just as important as on a site project using standard geophysical sensors, although the differing processes require differing quality procedures. Quality is required for each step in the process—dynamic, cued data collection, feature extraction, and classification. If all of the geophysical classification processes meet the quality requirements, the project team can have a high degree of confidence in the results from the use of geophysical classification at the site.

Quality considerations for the collection of high-fidelity geophysical data over each anomaly also require verification that all equipment checks and warm-up procedures are performed satisfactorily for the advanced geophysical equipment. Because advanced sensors have multiple transmitters and receivers, site personnel must verify that all relevant transmitters and receivers are operating properly.

Also ensure the proper placement of the instrument over an identified anomaly by taking into account target depth and size, as well as the physical size of the instrument's transmitters and receivers. For example, some advanced EMI instruments should not be more than 40 cm off-center over a small, shallow anomaly to collect high-fidelity geophysical data. In addition, the signal-to-noise ratio should be high enough to extract features in the data. Furthermore, the IVS can be used to measure the repeatability of the principal axis polarizabilities. The root-mean-square deviation of the daily polarizability measurements should be less than 10% to guarantee quality. Another method that has been used to verify the quality of the work performed using the IVS has been to ensure the daily generated model parameters of the items ISOs or munitions in the strip match the library parameters within 95%.

Blind seeding can also assess the quality of the identified features. The blind seeds' size and shape can be compared to the estimated targets' size and shape to ensure the reliability of these estimates. For instance, 37 mm blind seeds should have similar extracted features that are distinct from 75 mm blind seeds. Note that earlier small ISOs were made out of schedule 40 pipe nipples, but that small ISOs that are schedule 80 pipe nipples are now used to simulate the thicker walls of munitions. The medium and large ISOs are schedule 40 pipe nipples.

Blind seeding can build confidence in the development and quality of the classifier and can verify work in production areas. Typically, at least one blind seed should be encountered on a daily basis by each production team. The seeds used should reflect the types of munitions expected to be encountered at the site (i.e. site TOI). To assess an anomaly's classification (i.e. remove or leave in place), verify that all blind seeds are properly classified and that other items dug fit the expected shapes and sizes from the classifier. This process includes digging an agreed upon number of anomalies that have not been classified as a munition to confirm proper classification. The QC seeds are known by the contractor conducting the classification, but are blind to the analyst responsible for selecting TOIs. The QC seeds are considered verification seeds. The QA seeds are blind to all aspects of the contractor conducting the classification and are considered validation seeds. The verification seeds insure that the appropriate TOI/non-TOI threshold was identified. The validation seeds show that the features that were the basis for the classification of each item were correct.

4.6 Anomaly Reacquisition and Investigation

Anomaly reacquisition occurs once the DGM process has produced a map of the site or the analog (mag and dig) geophysics process is complete and subsurface anomalies are typically marked with pin flags or other marking methods that have the target number from the list. The UXO technicians navigate to the anomaly location using GPS or visually locate each pin flag and then excavate the overburden to uncover the anomaly source. The results of the dig (item identification, depth, orientation, etc.) are recorded. The excavated item is identified and segregated for proper treatment/disposal and is removed and properly disposed of. Prior to backfilling, the excavation is QC checked to ensure that additional anomalies do not remain in the area. The excavation is generally backfilled at that point and the site is restored to the specifications required in the approved project plans. Chapter 6 discusses removal and treatment technologies in more detail. It is important to remember the RI will involve limited removal and treatment of MEC/MPPEH and that the amount will be much less than the selected remedy for the site.

4.7 MC Sampling Techniques

Generally, MC in soil is very heterogeneous in spatial distribution, and is related to a low-order detonation that exposes a munitions filler. The actual distribution of MC is dependent on the overall number of low-order detonations, the degree of combustion, and the condition of the munitions item itself. Concentrations in soil may range from non-detect (with detection limits (DL) generally on the order of 0.5 parts per million [ppm]) to percent levels (i.e., greater than 10,000 ppm); concentrations may vary significantly within a short distance, and actual chunks of explosive filler may be present.

Data generated at munitions sites have shown that most MC from low-order detonations is found in the top 2 inches of soil, and that sampling deeper than 6 to 12 inches bgs is not warranted. However, alternate depths could be required based on erosion, surface grading, and other factors. In addition, if the need for MC characterization is associated with a buried MEC item, then sampling for MC should be biased towards the depth at which the MEC item was identified. Soil sampling should be conducted using standard hand or mechanical sampling techniques and following appropriate equipment decontamination protocols.

Critical decisions to make when characterizing soil for MC is whether to remove vegetation fragments and/or sieve soil samples. Certain analytical guidance (i.e., SW8330B [28]) recommends retaining vegetation to account for MC particles that may adhere to the vegetation. Alternatively, it is more typical during field sampling to remove vegetation from soil samples, and this is generally favored by the analytical laboratory. SW8330B recommends sieving and grinding an entire soil sample (i.e., from all incremental sampling locations) prior to subsampling for specific analyses, either in the field or at the laboratory [28].

If GW sampling is conducted, it should be conducted by installing temporary or permanent GW monitoring wells and sampling the wells in accordance with standard industry methods. Low-flow GW sampling is generally considered the industry standard GW sampling approach, and is described in EPA *Low-Flow (Minimal Drawdown) Groundwater Sampling Procedures* [38]. Any other media that are sampled (e.g., surface water or sediment) should also be sampled in accordance with industry standard approaches. If conducting GW (or surface water) sampling, a critical decision is whether to filter samples in the field or at the laboratory to ensure analysis of only the dissolved fraction. If filtration is conducted, it should be conducted before the sample is chemically preserved in any way.

Ultimately, sample preparation decisions should be made on a site-specific basis, should be determined during the systematic planning process to ensure data usability, and should conform to the project SAP. Information is available in Appendix A of the SW8330B method guidance document which describes collecting a representative sample for analysis of MC. Studies were conducted in support of this guidance primarily at active military and BRAC sites by USACE ERDC CRREL. Other information related to laboratory subsampling is available in EPA *Guidance for Obtaining Representative Laboratory Analytical Subsamples from Particulate Laboratory Samples* [39].

4.8 Sample Shipping Considerations

Raw explosive material and environmental samples with an explosive hazard cannot be shipped to off-site laboratories using normal shipping procedures. Special packaging and transportation procedures are required to ship such material.

There are on-site methods that can be used to determine if a sample contains any explosive constituent above the explosive limit. These methods include:

- Expray™ test kits
- Colorimetric test kits
- Immunoassay test kits

The Expray™ kit is the simplest screening kit for determining the presence or absence of explosives. Colorimetric test kits can be used primarily for TNT and RDX, and the results have been demonstrated to correlate well with standard laboratory analytical methods for these constituents. Immunoassay test kits are available specifically for TNT and RDX only, but are more selective than colorimetric test kits. The results are given in a concentration range, with ranges in general agreement with standard analytical methods for these constituents. Table 4-7 provides a summary of potentially usable field tests for MC.

4.9 Analytical Methods

Analytical methods for evaluating MC in environmental samples should be based on the munitions-related activities conducted at the MRS, the types of munitions used, and the fill of those munitions. In most cases, it would be optimal to only analyze for the specific constituents expected based on the munitions items used at the MRS. In the event that this is not practical, then full-suite analyses should be conducted. For example, analysis of metals should be limited to those metals reasonably assumed to be present based on the munitions of interest. Specific analytical needs should be coordinated with the project stakeholders prior to conducting field work. Other appropriate analytes should be determined using the background data generated.

Table 4-7 provides commonly evaluated MC and the analytical methods most appropriate to detect the constituent. The analytical methods summarized in Table 4-7 include laboratory and field tests. Field analytical methods can be used to characterize MC at an MRS, and because of the heterogeneous nature of MC and the more rapid turnaround time relative to an off-site laboratory, can be a cost-effective analytical tool. However, field analytical tools do not generally have DL as low as fixed laboratory methods, and users of field analytical tools must be properly trained.

Off-site laboratories should have experience handling MC samples and must be compliant with the DoD QSM for Environmental Laboratories [10]) through the Environmental Laboratory Accreditation Program.

4.9.1 <u>Data Validation</u>

Analytical data from MC characterization activities should be managed and validated following CERCLA and RI/FS guidance for IR sites and all applicable state or other regulatory requirements. Other resources for data management and validation that should be followed are EPA *Guidance on Environmental Data Verification and Data Validation* [40], the *Navy Installation Restoration Chemical Data Quality Manual* [41], the *National Functional Guidelines for Organic Data Review* [42], *Laboratory Data Validation Functional Guidelines for Evaluating Inorganic Analyses* [43], and the *DoD QSM for Environmental Laboratories* [10] mentioned in the previous paragraph. These procedures will ensure the appropriateness of the procedures used to generate data and the ultimate usability of the data.

It is recommended that a minimum of 10% of analytical data is validated fully (i.e., Level IV). This will support risk assessment and ultimate site closure. Staged electronic data deliverables should be generated and reviewed, and ultimately data should be transferred and stored in the Naval Installation Restoration Information Solution (NIRIS).

Table 4-7. Common Analytical Methods for MC

METHOD NO.	TITLE	COMPOUND
Common Field Tests		
SW4050	Trinitrotoluene (TNT) Explosives in Soil by Immunoassay	TNT
SW4051	Royal Demolition Explosive (RDX) in Soil by Immunoassay	RDX
SW6200	Field Portable X-Ray Fluorescence Spectrometry for the Determination of Elemental Concentration in Soil and Sediment	
SW8515	Colorimetric Screening Method for TNT in Soil	TNT
SW8510	Colorimetric Screening Procedure for RDX and Octhydro-1, 3, 5,7-Tetranitro-1, 3, 5, 7-Tetrazocine (HMX) in Soil	HMX, RDX
N/A	Expray™	
Common Laboratory Analytical Methods		
SW6010C	Trace Metals Analysis by Inductively Coupled Plasma Atomic Emissions Spectrography	lead, copper, antimony, zinc, aluminum
SW6020A	Inductively Coupled Plasma – Mass Spectrometry	lead, copper, antimony, zinc, aluminum
SW6850	Perchlorate in Water, Soils and Solid Wastes Using High Performance Liquid Chromatography/Electrospray Ionization/Mass Spectrometry or Chromatography-Electrospray Ionization Tandem Mass Spectrometry	perchlorate
SW6860	Ion Chromatography / Electrospray Ionization/Mass Spectrometry	perchlorate
SW7470A/7471B	Mercury in Liquid Wastes (Manual Cold-Vapor Technique)	mercury
SW8330A	Nitroaromatics and Nitramines by High Performance Liquid Chromatography	HMX, RDX, 1,3,5-TNB, 1,3-DNB, tetryl, NB, TNT, DNTs, NTs
SW8330B	Nitroaromatics and Nitramines by High Performance Liquid Chromatography	HMX, RDX, 1,3,5-TNB, 1,3-DNB, tetryl, NB, TNT, DNTs, NTs, NG, PETN, 3,5-DNA
SW8332	Nitroglycerin by High Performance Liquid Chromatography	NG
SW8095	Explosives by Gas Chromatography	HMX, RDX, TNT, DNTs, NTs, 1,3,5-TNB, 1,3-DNB, tetryl, NG, PETN, NB
SW8321A[a]	Explosives by High Performance Liquid Chromatography/Mass Spectrometry	HMX, 1,3,5-TNB, 1,3-DNB, tetryl
SW8321B	Solvent-extractable Non-volatile Compounds by High Performance Liquid Chromatography/Thermospray/Mass Spectrometry or Ultraviolet Detection	RDX, NB, TNT, DNTs, NTs, NG, NH_4 picrate, picric acid, PETN, MNX, DNX, TNX, NQ, 3,5-DNA
U.S. EPA 331.0	Determination of Perchlorate in Drinking Water by Liquid Chromatography Electrospray Ionization Mass Spectrometry	perchlorate
U.S. EPA 332.0	Determination of Perchlorate in Drinking Water by Ion Chromatography with Suppressed Conductivity and Electrospray Ionization Mass Spectrometry	perchlorate
U.S. EPA 529	Determination of Explosives and Related Compounds in Drinking Water by Solid Phase Extraction and Capillary Column Gas Chromatography /Mass Spectrometry	RDX, TNT, DNTs, NTs, 1,3,5-TNB, 1,3-DNB, tetryl, NB, 1,3-DNA

(a) This method typically is cited for high performance liquid chromatography/mass spectrometry of explosives. However, no published version includes explosives.

4.10 MEC Hazard Analysis

Both CERCLA and the NCP call for an assessment of the risks associated with the pollutants or contaminants of concern at a site. While a traditional risk assessment determines the chronic risk associated with exposure to the contaminants, it does not address the acute hazards resulting from accidentally detonating a munitions item. These acute hazards are addressed by conducting a MEC HA.

The MEC HA addresses human health and safety hazards associated with land-based, non-chemical explosive munitions. The MEC HA does not address environmental or ecological concerns that might be associated with MEC, explosives or hazards at underwater sites, or explosive or other hazards associated with stockpile or non-stockpile CWM. In addition, the MEC HA does not determine the degree of cleanup required at a site. Selection of the remedy is based on evaluating several alternatives or combinations of alternatives, along with assumptions about LUCs through the CERCLA nine-criteria process. The CERCLA nine criteria evaluation process is presented in Section 7.

Information from the MEC HA supports the CERCLA nine criteria evaluation and the associated remedy selection process. MEC HA provides input to the threshold criteria of protection of human health and the environment and compliance with applicable or relevant and appropriate requirements (ARAR). In addition, information provided by the MEC HA specifically assists in understanding four primary balancing criteria: long-term effectiveness; short-term effectiveness, implementability; and reduction of toxicity, mobility, or volume through treatment.

The MEC HA uses a relative numeric approach and is structured around three components of potential explosive hazard incidents:

- **Severity.** The potential consequences (e.g., death, severe injury, property damage, etc.) of an MEC item functioning.
- **Accessibility.** The likelihood that a receptor will be able to come in contact with an MEC item.
- **Sensitivity.** The likelihood that a receptor will be able to interact with an MEC item such that it will detonate

Table 4-8 provides the MEC HA values that were reached by consensus of the MEC HA technical working group.

The MEC HA analysis generates a qualitative score for a specific site and set of conditions assumed to be present at the site, or conditions that are possible in the future at the site. This score falls within one of four defined ranges of scores, called hazard levels, which are defined as shown in Table 4-9. MRSs in Hazard Level 1 have the highest potential explosive hazard conditions, followed by Hazard Level 2, 3, and 4 having a high, moderate, and low potential for explosive hazard conditions, respectively.

The Office of the Under Secretary of Defense issued direction for use of the MEC HA in the memorandum dated January 26, 2009, "Trial Use of the Interim Munitions and Explosives of Concern Hazard Assessment (MEC HA) Methodology". The identified time period in the memorandum has passed, but the memorandum or a follow on memorandum rescinding the original memorandum has not been issued. If the MEC HA is used an evaluation of the use (impact on the project) must be submitted.

Table 4-8. MEC HA Input Factor Maximum Scores and Resulting Weights

Explosive Hazard Component	Input Factor	Maximum Scores	Weights
Severity	Energetic Material Type	100	10%
	Location of Additional Human Receptors	30	3%
	Component Total	***130***	***13%***
Accessibility	Site Accessibility	80	8%
	Total Contact Hours	120	12%
	Amount of MEC	180	18%
	Minimum MEC Depth/Maximum Intrusive Depth	240	24%
	Migration Potential	30	3%
	Component Total	***650***	***65%***
Sensitivity	MEC Classification	180	18%
	MEC Size	40	4%
	Component Total	***220***	***22%***
	Total Score	**1,000**	**100%**

Table 4-9. MEC HA Hazard Levels

Hazard Level	Maximum Score	Minimum Score
1	1,000	840
2	835	725
3	720	530
4	525	125

As noted in section 2.2, the ACOE is currently in a trial period of the "Study Paper: Decision Logic to Assess Risks Associated with Explosive Hazards, and to Develop Remedial Action Objectives for Munitions Response Site." The Navy is not currently trialing this paper.

5.0 UNDERWATER REMEDIAL INVESTIGATION

This section provides guidance for implementing the RI at underwater MRSs. The objectives and general steps in the RI are the same for both terrestrial (see Section 4) and underwater MRSs. However, several site-specific considerations need to be evaluated and addressed at underwater sites. Underwater MRSs are considered shallow water areas where munitions releases are known or suspected to have occurred, where Navy actions are responsible for the release, and where munitions are covered by water no deeper than 120 ft. This depth is used because it represents the typical safe depth limit of recreational divers using air as a breathing medium. Note that MRSs located in waters between high and low tides are considered terrestrial sites. In addition, the following types of sites are not considered underwater MRSs:

- A site that is part of, or associated with, a designated operational range (terrestrial or water range)
- A designated water disposal site
- A FUDS
- A result of combat operations
- A maritime wreck
- An artificial reef

This section will discuss the role of the CSM in the RI at underwater MRSs, site-specific considerations that may impact the RI field work, positioning, navigation, and detection technologies for investigating underwater MRSs, and the steps used in data collection operations during the RI.

It is important to remember that the investigation approach for an underwater MRS must be adapted to the environment in which the investigation is conducted. A small pond or lake will not be investigated the same way as for an area with significant wave action and strong currents.

5.1 Conceptual Site Model

As discussed in Section 3.2.2, the CSM establishes a working hypothesis of the nature and extent of contamination (DMM, MEC/UXO, and MC), including the types of contaminants (*sources*), routes of contaminant migration with a focus on geologic and hydrologic models as well as MEC mobility (*pathways*), and potential current and future receptors and exposure routes (*receptors*). Development of the CSM is an iterative process. It is initially developed during the PA/SI using historical information on site use and the results of any preliminary investigations, and it is continually revised and updated as new investigations and data become available.

The CSM can be documented in a tabular format that summarizes the potential contaminant sources, migration pathways, and human and ecological receptors at a site, or the CSM can be documented in a graphical format, as shown in Figure 5-1. Figure 5-1 is an example CSM for an underwater MRS that shows the source of contamination (hazards and potential MEC associated with bombs and projectiles), the migration pathway (wave action that can change the location of hazards), and potential human and ecological receptors (unauthorized divers, recreational and commercial fishing and shell fish harvesting, shoreline and anchorage visitors, and aquatic organisms such as corals, seals, etc.).

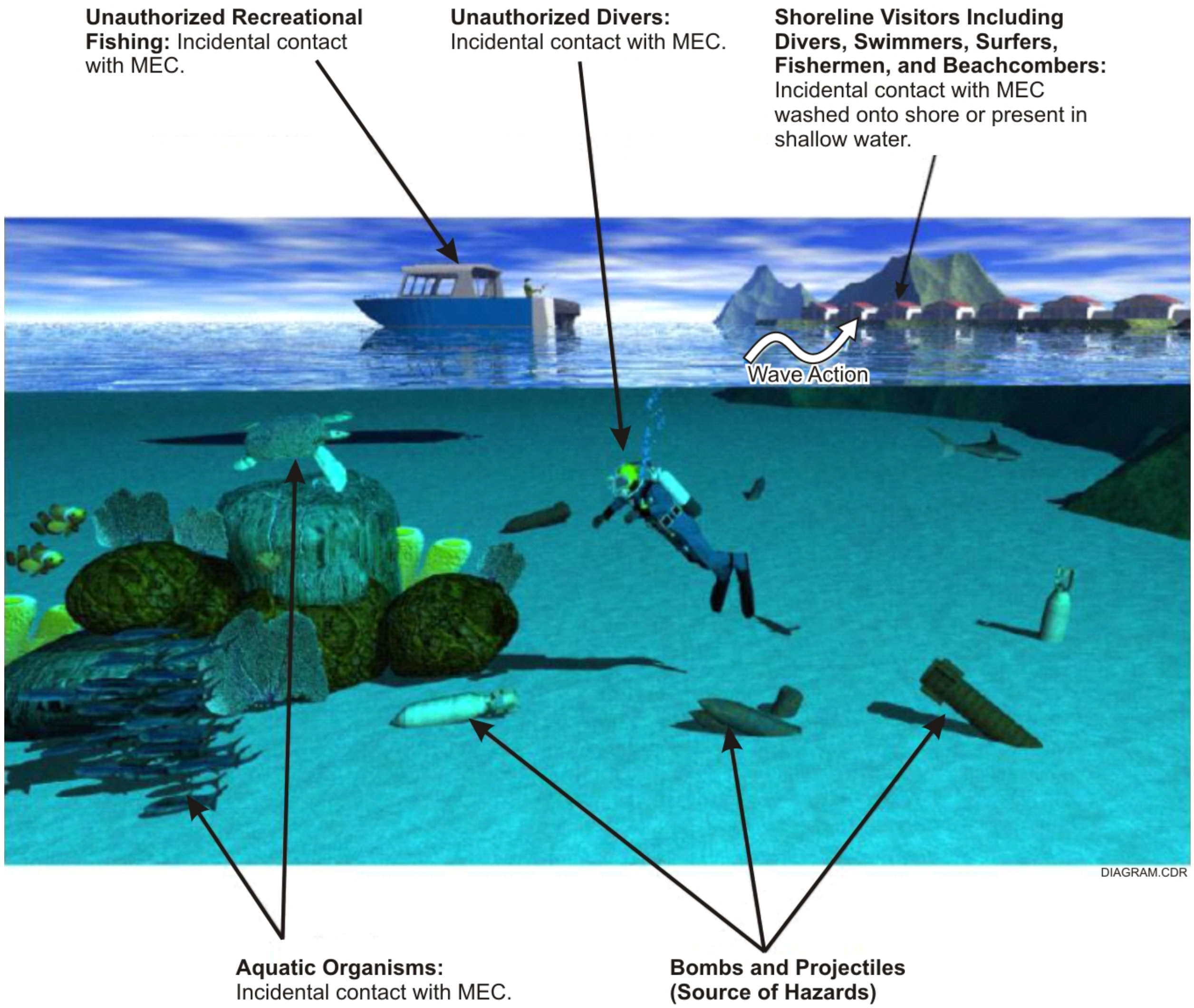


Figure 5-1. Example CSM for Underwater MRS

5.2 Underwater Site Investigation Planning

As discussed in Section 4, the nature and extent of MEC is assessed through the investigation, and the data are evaluated to characterize the potential threat to human health and/or the environment. When developing the plan for implementation of the investigation at an underwater MRS, several site-specific conditions should be considered, including prevailing winds and seas state, degree of exposure on the bottom or the beach from erosion or movement, tidal fluctuations, water depths and site bathymetry/terrain, geology, habitat, biota and vegetation. Logistical considerations should include availability of moorings, harbors, and fuel supplies, availability of medevac, and locations of the nearest recompression chamber when using divers.

Tidal and seasonal weather changes may allow for only certain windows of time when work can be efficiently conducted. Tidal fluctuations result in varying depths of water at a site and also influence the set and drift (direction and speed) of tidal currents in a waterway. All of these factors may impact mobility of underwater MEC and the type of detection technology selected for use at an underwater MRS. Tidal information for a specific site can be determined from tidal zoning and real and post processed of data from high accuracy global navigation/globe navigation satellite systems. Tidal zoning refers to the practice of dividing a hydrographic survey area into discrete zones or sections, each one possessing similar tidal characteristics. Data from known tide stations are used to extrapolate/interpolate tidal characteristics in the hydrographic survey area by using correction factors in the form of time differences and range ratios. Tide station data for coastal areas and the Great Lakes can be found at the NOAA Tides and Currents webpage.

In addition to the tides and currents, other site-specific information should be well understood to ensure proper planning for the investigation activities. One type of survey that can be performed in advance of the RI data collection is the bathymetric survey. Completion of a bathymetric survey provides an understanding of the underwater topography so that appropriate investigation techniques can be selected when planning the RI activities. Steep slopes in the underwater topography can present limitations for detection instrumentation, whereas large, flat areas can be more effectively investigated with towed or vessel mounted systems. Figure 5-2 illustrates how data from a multibeam echosounder (MBES) bathymetric survey can be presented to assist in planning the RI activities. Underwater geology and vegetation can also play a role in selecting appropriate investigation methods. Magnetometers are sensitive to iron-bearing minerals that may be contained in the seafloor, and the density of vegetation will also determine the type of investigation technology used during the RI. Each site is unique and requires a unique combination of investigation technologies based on site-specific conditions.

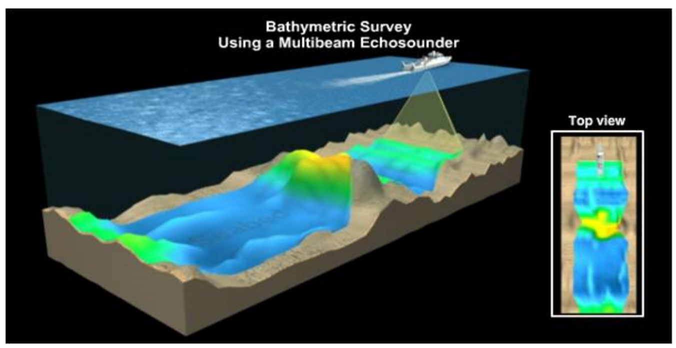


Figure 5-2. Example MBES Bathymetric Survey

Additional considerations for planning and scheduling underwater investigation activities include the presence of endangered or protected species and habitat, seasonal commercial and recreational uses of the site, project plan review and approval times for regulators and stakeholders, and availability of logistics support relative to the MRS. Adequate travel time in the work day schedule to account for travel from the nearest mooring/harbor to the MRS should be considered. Also consider Naval security, ship schedules, and commercial/recreational traffic when planning the project schedule. Activities should also be planned accordingly based on fuel availability and resupply needs while away from shore.

Seasonal weather patterns may exert influences on local ecosystems that may affect underwater access and work site logistics. For example, heavy rainfall may cause runoff and sedimentation that would impede underwater visibility. Fog or strong storms, including hurricanes, can disrupt work site conditions for a definite amount of time before normal conditions are restored. Secure locations near the MRS should be identified in the event of rough weather on the water. Rough weather can generally be avoided by obtaining a weather forecast prior to setting out. However, a sudden unexpected storm may occur, so plans should be made to ensure worker safety during such an event. Be mindful of signs of approaching rough weather, such as increasing clouds, wind and white cap waves. In the event of such unexpected rough weather, secure locations include the shore, a harbor, or the lee of an island where the wind cannot generate large waves.

MRS investigations must be cognizant of habitat structure and the presence of protected species. Habitat, protected species, and the migratory patterns of economically important species must be identified to properly plan detection surveys, equipment operations and remediation actions. Protected habitats and species will dictate project timing, extent of operations and appropriate course of mitigation.

The technology and investigation methodology for underwater sites is an evolving science. A combination of sensor technologies and platforms will most likely provide the best characterization data. Prior to planning an underwater investigation, RPMs are encouraged to consult with their Munitions Response Workgroup member to ensure the latest technology and most cost effective methodology is employed.

5.2.1 Transect Design

The overall sampling design for investigation activities at an underwater MRS includes development of the transect design and selection of the detection technology. The sampling design and rationale should be developed based on site-specific conditions and documented in the RI Work Plan.

The transect spacing developed as part of the sampling design must ensure proper site characterization to determine the nature and extent of MEC contamination present. Elements of the CSM, site-specific conditions, and the identified investigation objective will be used in determining the transect design. For example, the potential mobility of items due to wave action or tidal currents will need to be considered and assessed when identifying the survey area and timing of the investigation. Survey work at one location was postponed until low wave height conditions allowed access to portions of the site exposed to the waves and areas where mobile items may have accumulated over time.

A uniform transect survey is best suited for sites with easy terrain and minimal underwater vegetation. This approach uses a semi-fixed path that is followed from pre-determined start and end points. The transects should be oriented perpendicular to the long axis of the area of potential concern (AOPC) in order to maximize the chance of fully defining the area. AUVs can be programmed to conduct surveys using terrain following after bathymetric data is collected by the AUV.

Another option is the meandering path approach (Figure 5-3). In this approach, a survey vessel/diver meanders throughout the location until the mapped area captures the AOPC. The meandering path design is best suited for sites with difficult bottom terrain and dense underwater vegetation, as it allows for meandering around steep slopes and dense vegetation. Surveying around the densely vegetated areas reduces vegetation removal and potential ecological impacts. Implementation of the diver based (not vessel based) meandering path design results in poor positional accuracy, which will negatively impact the reacquisition process and increases costs at a later date.

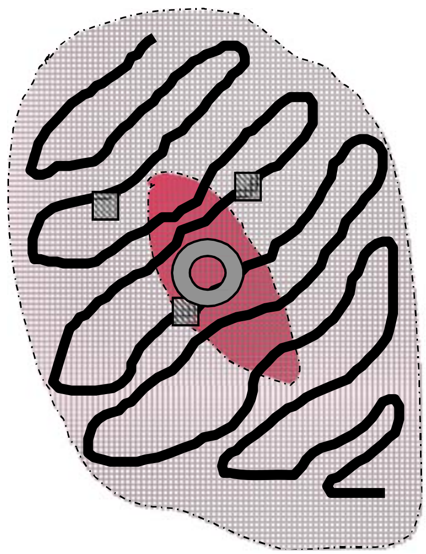


Figure 5-3. Example Meandering Path Investigation Approach

Finally, a mini-grid survey can also be selected as part of the sampling design. The objective of the mini-grid survey is to determine the amount and type of MEC present within a known AOPC location. Typically, there are one or more mini-grids located within each AOPC. The statistical tools discussed in section 4.1.2 can also be used for underwater transect and mini-grid survey design.

5.2.2 <u>Anomaly Detection Technologies</u>

In addition to identifying the appropriate transect design approach, the appropriate anomaly detection technology will need to be identified. Selection of the appropriate detection technologies will be based on site-specific information from the CSM, the types of anomalies expected to be encountered, and the objectives of the investigation. Figure 3-2 is an example of some technology selection criteria. The primary types of anomaly detection technologies available for use at underwater MRSs include sonar, laser line scanner (uncommon), and magnetometer/EMI. In addition, the platform for these technologies must be selected (diver, surface vessel, surface or subsurface towfish, sled, autonomous surface vehicle (ASV), ROV, AUV along with the navigation/location technology. Each of these technology options are discussed further in the following sections.

Sonar (Sound Navigation and Ranging)

Active sonar uses a sound transmitter and a receiver to create a pulse of sound (ping), and then the user listens for reflections (echo). Figure 5-4 demonstrates this action. This sound propagation technique enables detection of objects under the surface of the water, such as MEC located on the seafloor. A sonar projector consists of a signal generator, power amplifier, electro-acoustic transducer/array and typically a beamformer, which may be swept to cover the required search angles. In general, higher frequencies provide better resolution for anomaly detection, but are attenuated faster.

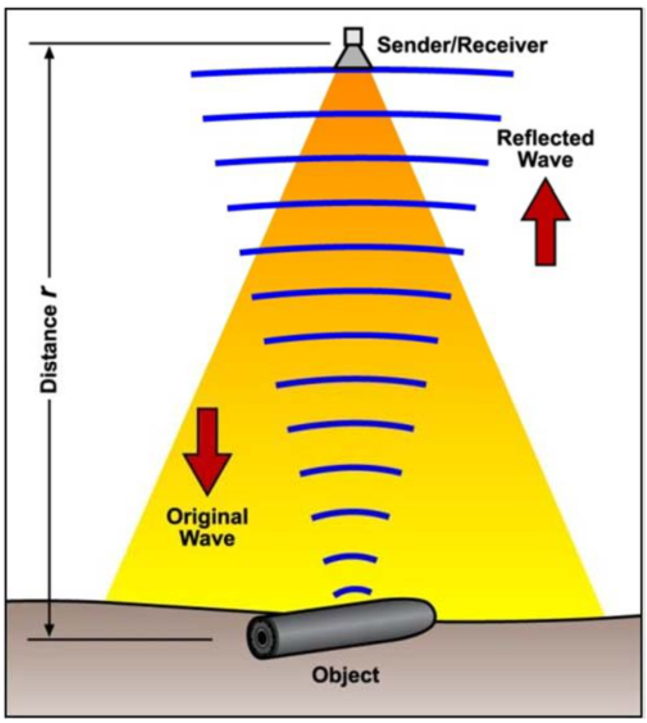


Figure 5-4. Sonar Operation

Numerous corrections must be made to the sonar measurements to account for variability in the ocean or movement of the vessel. Corrections for draft, heave, roll, pitch, tide, and sound velocity, must all be applied in real time or during data processing to ensure accurate results from sonar surveys (Figure 5-5).

Several types of sonar are available for use depending on site-specific characteristics:

- Single-beam;
- Multi-channel sweep single beam;
- Multi-beam;
- Interferometric;
- Side-scan;
- Imaging;
- Sub-bottom Profiling; and
- Synthetic Aperture.

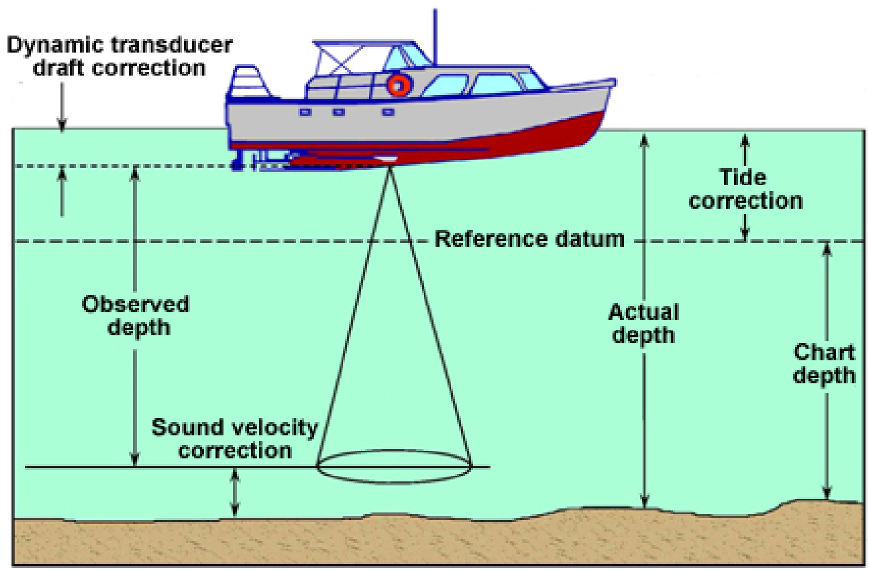


Figure 5-5. Corrections Applied to Sonar
(Graphic courtesy of NOAA)

Figure 5-6 shows how two of these types of sonar operate.

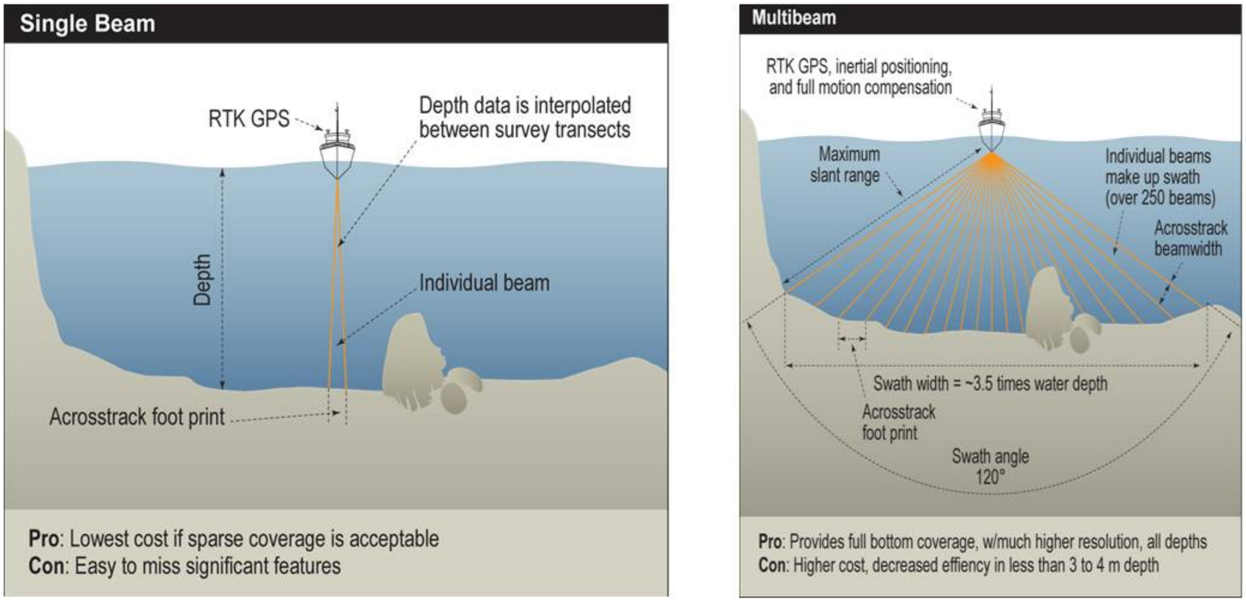


Figure 5-6. Single Beam and Multibeam Sonar

Single beam sonar is commercially available as inexpensive "depth finders" on recreational and commercial watercraft. Transducers may be mounted on boat sterns or through the hull with monitors on dashboards or cabin bulkheads for rapid determination of bottom depths. However, single-beam sonar does not produce data of sufficient quality for anomaly detection at underwater MRSs.

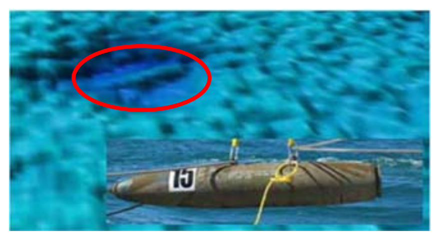


Figure 5-7. 3-D Multi-Beam Sonar Image of Bomb

Multi-beam sonar is also widely available and inexpensive. This method produces high resolution bathymetric data that can be used for follow-on surveys and may detect MEC protruding from the bottom surface (Figure 5-7). The swath of multi-beam sonar is typically limited to three to five times water depth (i.e., an area 30 to 50 m wide can be covered by multi-beam sonar at a depth of 10 m). Therefore, when working in shallow water (e.g., less than 10 m), it can be difficult to efficiently attain full bottom coverage (e.g., more transects are needed to obtain full bottom coverage).

Interferometric sonar, also referred to as phase differencing bathymetric sonar, is one tool that may provide improved efficiency over multi-beam sonar in shallow water. However, while interferometric sonars are capable of providing wide-swath coverage in shallow water with swaths of 10 to 15 times instrument altitude, the acquired data have a resolution which is typically significantly less than multi-beam sonar. Similar to multi-beam sonar, interferometric sonar also produces high resolution bathymetric data that can be used for follow-on surveys and may detect MEC protruding from the bottom surface. A comparison of multi-beam and interferometric sonar is presented in Table 5-1.

Side-scan sonar is another widely available sonar technology. Standard side-scan uses a sonar device that emits conical or fan-shaped pulses down toward the seafloor across a wide angle perpendicular to the path of the sensor through the water, which may be towed from a surface vessel or mounted on the ship's hull. Side-scan systems can be configured to map along both sides of the vessel, and newer systems also now map under the vessel or towfish.

Table 5-1. Comparison of Multi-beam and Interferometric Sonar

SPECIFICATION	MULTI-BEAM	SPECIFICATION	INTERFEROMETRIC
Frequency	2.25 MHz	Frequency	500 kHz
Field of View	45ºx1º	Max Coverage	Up to 12x depth
Max Range	30 ft	Max Range	50 m
Beam Width	1ºx1º	Beam Width	0.5º
Number of Beams	256	Depth Resolution	1.5 mm
Beam Spacing	0.18º	Pulse Length	32 to 224 μs
Time Resolution	0.39 in	View Angle	240º
Max Update Rate	40 Hz	Max Update Rate	30 Hz

Similar to multi-beam and interferometric sonar, side-scan sonar generates high resolution images of the seafloor that may detect MEC protruding from the bottom surface. However, cluttered environments such as coral, rocks, and vegetation can affect the ability to identify MEC like objects using all types of sonar.

Imaging sonar is available and relatively inexpensive sonar technology. Imaging sonar transmits sound pulses and converts the returning echoes into digital images, much like a medical ultrasound sonogram. The advantage of imaging sonar is the ability to “see” what is happening through dark or turbid water. Imaging sonars have shorter usable range but higher resolution than side-scan and multi-beam sonar technologies. One version of an imaging sonar is the 3D mechanical sector scanning sonar. These sonars create high-resolution imagery of underwater areas, structures, and objects. This technology creates 3D point clouds underwater in low or zero visibility conditions with 3D laser-like scanning capabilities. These units are compact and lightweight that allows them to be easily deployed on either a tripod or a ROV. The scanning sonar head and integrated mechanical pan and tilt mechanism generate both sector scans and spherical scan data. Table 5-2 summarizes the specifications for one hand-held imaging sonar system.

Table 5-2. Summary of Imaging Specifications

SPECIFICATION	ARIS 3000
Frequency	1.8 or 3 MHz
Field of View	30º x 15°
Range Resolution	down to 3 mm
Beam Width	0.25°
Number of Beams	128
Max Frame Rate	15 frames/sec
Dimensions	26 x 16 x 14 cm

Sub-bottom profiling is able to look beyond the surface bathymetry and define different sediment layers beneath the surface that can help identify where a MEC item may be buried. Sub-bottom profilers can be towed behind the supporting vessel, floated on the water surface, or mounted on the vessel hull or a pole. Sub-bottom profilers provide a straight line look (i.e., 2-D profile) through the seafloor, much like slicing through a layered cake. By employing a sound-emitting device and array of receivers, three-dimensional maps can be produced. The size of expected MEC at the underwater MRS should be considered, because all but the largest MEC items are too small to identify with this technology.

Synthetic Aperture Sonar (SAS) systems operate by coherently combining the backscattered acoustic energy (or echo) from multiple successive pings (or transmissions) as the “Physical” sonar aperture and platform moves through the water. Figure 5-8 illustrates this concept and augments the topics briefly discussed next.

In standard linear track SAS imaging techniques, the number of echoes/pings coherently combined is varied with range. This effectively produces a “Synthetic” aperture whose extent or length varies with range resulting in imagery of constant along-track or cross range resolution (sometimes also referred azimuth resolution). Because of this, SAS systems can produce geometrically correct and highly detailed underwater imagery. In many applications, SAS systems can be more advantageous than standard real aperture side-looking (RAS) sonar systems. At low speeds in particular, typical of AUVs to lengthen endurance, for a given along-track resolution, SAS systems can produce a higher area coverage rate (ACR). This is because SAS systems can achieve longer ranges by operating at lower frequencies than RAS systems due to the lower absorption lower frequencies suffer in sea water. Another advantage of SAS systems is their inherent wider horizontal field of view or beamwidth, which allows them to “view” the targets over a wider horizontal sector than RAS systems can. The wider SAS beams allow image processing techniques such as multi-aspect SAS to reduce the likelihood of missing a target because of a poor viewing angle (target at a low reflectivity angle) and circular SAS (CSAS) to produce imagery with an impressive level of detail.

The top left subfigure 5-8 illustrates the trajectory of the sonar/platform. The top right subfigure 5-8 illustrates the characteristic “smile” type shape of target echoes as result of the varying two-way time to the target as function of sonar/platform location. The bottom right subfigure 5-8 illustrates the coherent summation process. The bottom left subfigure 5-8 illustrates the attainable differences in image quality between a Real Aperture Sonar and SAS.

The Office of Naval Research (ONR) synthetic aperture bottom mapping sonar (BMS) is an example of a SAS that has been used to survey munitions sites. The system, developed jointly by the Naval Surface Warfare Center Panama City Division (NSWC PCD) and the Applied Research Laboratory at the Pennsylvania State University (ARL/PSU), is owned by the U.S. Navy and

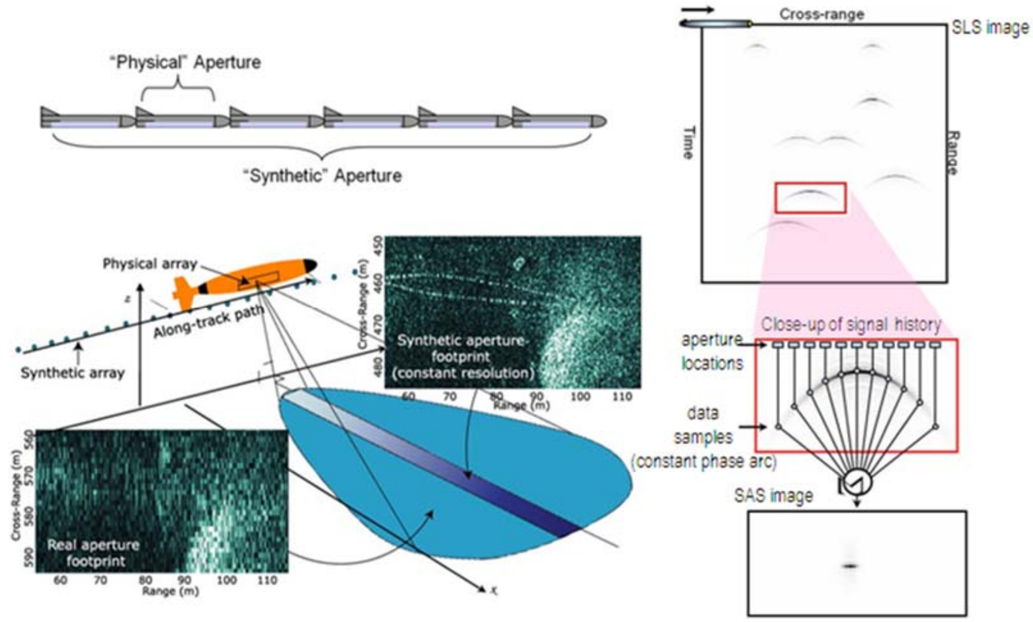


Figure 5-8. Synthetic Aperture Sonar Concept.

operated by NSWC PCD. The BMS is a sophisticated dual-frequency band, broadband, widebeam, interferometric SAS. With its dual-frequency bands, the BMS generates dual frequency high resolution imagery of the seabed and provides detection and classification capabilities against proud and shallow buried targets. The BMS can also generate fine scale bathymetric maps, and very high fidelity imagery by circumnavigating areas of interest using Circular SAS imaging techniques. Figure 5-9 shows the BMS along with its supporting AUV, the Remote Monitoring Environmental UnitS 12.75″ diameter (REMUS600), and BMS sample images. The REMUS600 was originally developed by the Oceanographic Systems Lab (OSL) Woods Hole Oceanographic Institution (WHOI) and is now commercially available from Hydroid Inc. Figure 5-10 shows additional sample images generated by the BMS.

As evident by the BMS sample images, wide beam multi-frequency SAS technology offers great capabilities for MEC investigations. As for any other sonar, the effective coverage width of the BMS system is a function of its design characteristics, and environmental and operational conditions such as speed of sound, water depth, altitude, etc. For the characteristics of the BMS/REMUS600 system, the system is best employed at water depths greater than 15 feet.

Buried Object Scanning Sonar (BOSS)

The BOSS is a downward looking sediment volume imaging SAS that features a broad-band low frequency Omni-directional acoustic projector and two, one meter long wings. Embedded in each one meter long wing is a 20-element hydrophone receive array. The BOSS system is shown in figure 5-11 along with its supporting AUV, the 12.75″ diameter Bluefin12. The BOSS sensor was originally developed by Florida Atlantic University. Variants of it are commercially available from EdgeTech.

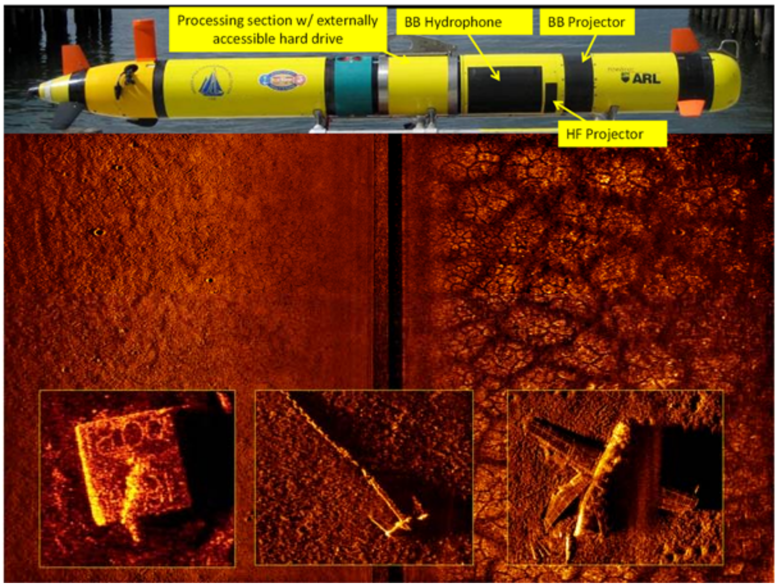


Figure 5-9. The BMS System and Example Images.

From left to right the bottom row of insets show a concrete block, anchor, and sunken Helldiver plane. The engraving on the block is visible and the anchor – nearly at maximum range. The figure background shows a mirrored comparison of the high frequency and broad-band images for a scene. Buried geological formations are visible using the broad-band lower frequency band.

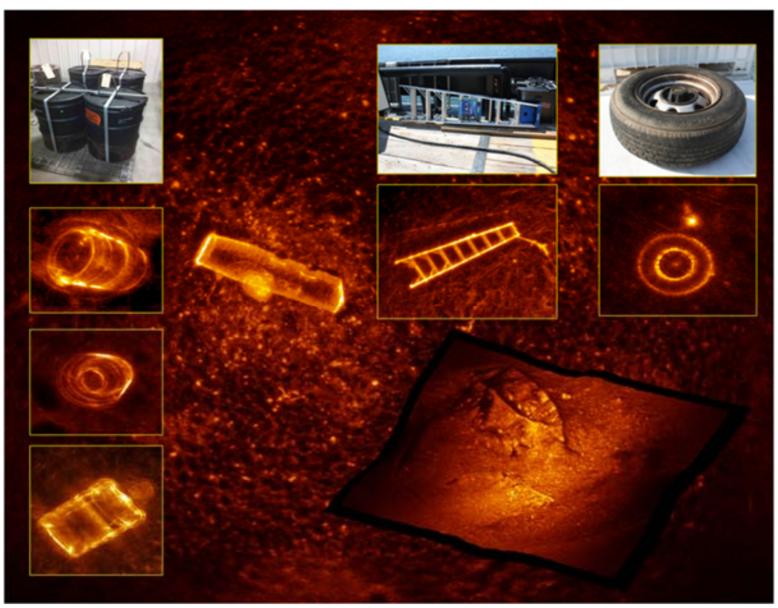


Figure 5-10: Examples of CSAS Imagery Generated Using the BMS System.

The left column shows several images of plastic and steel 55 gallon drums partially filled with concrete. Other images show a ladder, car tire, and boat overlaid on topography. The background image shows a beveled training cylinder.

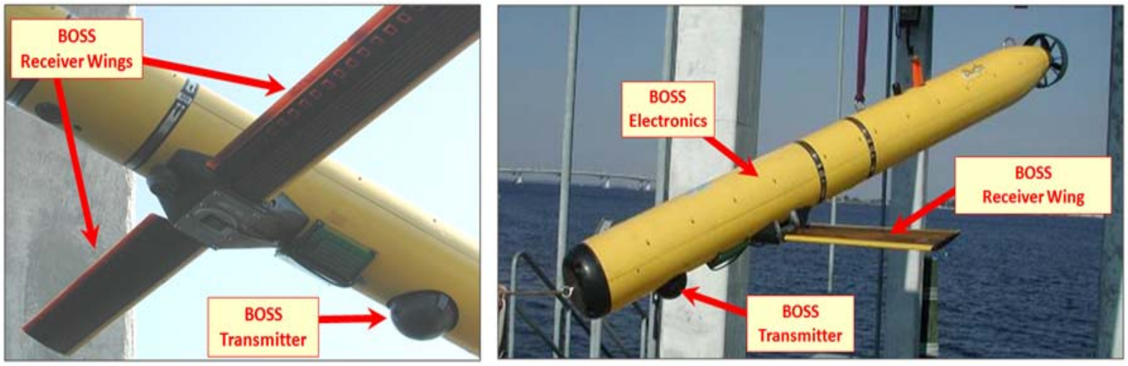


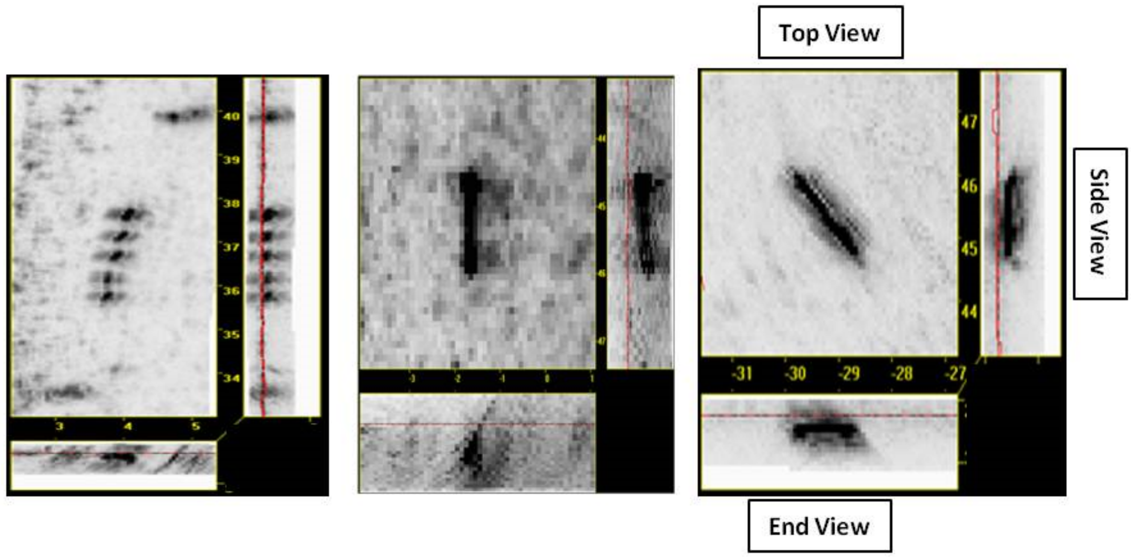
Figure 5-11: BOSS Sensor Integrated onto a Bluefin12 12.75-inch Diameter AUV.

The BOSS utilizes beam steering and synthetic aperture processing to generate multi-aspect Three-Dimensional (3D) imagery of the seafloor as well as proud, partially and fully buried objects. As the imagery is generated, it is stored in a 3D matrix with indices corresponding to along-track, cross-track, and depth. For visualization three orthogonal multi-aspect image projections are generated. The three projections are rendered as top view, a side view and an end view. Figure 5-12 illustrates examples of three different buried objects imaged by BOSS. Navy RPMs who are interested in using BMS or BOSS at an underwater MRS would need to coordinate with NSWC-PCD to perform the survey.

Parametric Sonar

Parametric sonar systems are particularly useful in shallow water areas. The sound source is physically small, but able to produce highly directive, low frequency sound beams that penetrate the sediment. Parametric sonars transmit two signals at slightly different high (primary) frequencies and at high sound pressures. Because of non-linearities in the sound propagation at high pressures both signals interact and new frequencies are generated. These are referred to as the secondary frequency (difference of the transmitted frequencies), and is low frequency which penetrates the sea bottom. Currently, ESTCP is testing a parametric sonar for shallow water detection of MEC.

It is important to note that the types of sonar used for investigation of underwater MRS do not adversely impact marine mammals that rely on echolocation. Echolocation is used for navigation, location, feeding, mating, defense, and communication by marine mammals. There have been concerns about the use of survey sonar and its effect on marine mammals. Common sonar acoustic sources typically operate in the 20 Kilohertz (KHz) to 32 KHz range, and typical bathymetric and imaging sonars operate between 100 KHz and one Megahertz (MHz). These frequencies are not considered harmful to marine mammals. These sonar signals are low power and/or above the hearing range of marine mammals. This is not a regulatory issue, but do give courtesy notice to the stakeholders with regard to this issue. Table 5-3 provides a comparison of sonars.



(a) (b) (c)

Figure 5-12: Examples of BOSS Imagery:

(a) 3D image of five flush-buried cylinders showing small variations in the end-to-end orientation of the buried cylinders, (b) fully buried large mine-like object in silt-mud sediment and (c) fully buried large mine-like object in sand sediment. The horizontal red line in the images represents the position of the seabed detected by the Doppler velocity log (DVL).

Visual Survey/Underwater Camera

Visual assessment methods using divers could be employed under favorable weather and diving conditions. Major considerations include the size of the area to be examined, the frequency of acceptable weather and diving conditions, and visibility at the site. Low turbidity at the site is desirable for conducting visual assessment.

Underwater camera technology ranges from handheld digital cameras with underwater housing and memory cards to tethered high-resolution video cameras with panel displays on support craft. Systems are also available for incorporating infrared light technology to assist in low light/low visibility scenarios and for laser scaling. Image post processing that can improve the final images.

Laser Line Scan

Laser line scan is an electro-optic imaging technique that produces high contrast underwater light field images. A laser line scan system consists of a sweeping blue-green laser (532 nm, 200 mW) mounted on a ROV or AUV to reflect light across the seafloor and generates a gray-scale image similar to black and white photography (Figure 5-13). The image resolution and swath width vary with water clarity and tow height above the sea floor (Table 5-4). Typically, the swath width is considered 1.4 times the height above the sea floor, and the survey rate is approximately 3 to 4 knots with 1 m accuracy along track.

Table 5-3. Example Sonar Technology Comparison Summary

TECHNOLOGY	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	RELATIVE COST	REPRESENTATIVE SYSTEMS
Side-scan	A sonar device that emits conical or fan-shaped pulses down toward the seafloor across a wide angle perpendicular to the path of the sensor through the water.	Will not identify munitions covered by sediment, plant growth, or rock. Can detect large items, but actual capabilities and limitations for detecting and classifying munitions are unknown.	**High:** Creates image of large areas of the seafloor, but munitions must be on surface (proud) and uncluttered by nearby environmental factors such as coral, rocks, and vegetation.	Low	Edge Tech 4125/4205 Klein 5900 Tritech SeaKing
Multi-beam Echo Sounder	A device which transmits a broad acoustic pulse from a specially designed transducer across the full swath across-track to determine the depth of water and the nature of the seabed.	Theoretically can provide enough detail to identify munitions on or proud of the water bottom, but capability, interferences, and limitations must be tested.	**High:** Produces high-resolution bathymetry data throughout the survey area.	Low to Medium	RESON SeaBat T50 R2Sonics 2024 Kongsberg Geoswath Imagenex
Scanning/Imaging	A high-definition imaging sonar that obtains near-video quality images for the identification of objects underwater.	Can assist ROV/AUV and divers with identification of munitions in turbid waters. Can detect small and large items depending on system used and distance from object. Object must be on or proud of the seafloor.	**High:** Allows for the identification of items of interest proud of the bottom.	Medium	Dual-frequency Identification Sonar (DIDSON), ARIS Blueview Imagenex
Sub-bottom Profiling	An instrument which projects a narrow sonar beam into the seafloor. Data are then combined with computerized control and mapping to allow archaeologists to record and replay a "virtual excavation" of a wreck site, that is a three-dimensional model, removable in layers, all in a computer without ever touching the wreck.	High-resolution sub-bottom systems have been used to identify buried objects, but not likely to detect munitions unless they are fairly large. Not economical because 100% coverage would be needed, but could possibly be deployed with other 100% coverage mapping.	**Low:** Allows for the identification and measurement of various sediment layers that exist below the sediment/water interface.	Medium	Bathy 2010 EdgeTech 3400/2200/2205 Kongsberg Geo Chirp II
Synthetic Aperture Sonar (SAS)	SAS combine a number of acoustic pings to form an image with much higher resolution than conventional sonars, typically 10 times higher.	SAS technology is still relatively new. Munitions detection capability versus proud targets has been demonstrated. Low frequency SAS has demonstrated detection of buried objects. Navy systems are high resolution	**High:** SAS moves sonar along a line and illuminates the same spot on the seafloor with several pings. Navy systems are only available through NSWC PC	Medium	Kongsberg HISAS 2040 Raytheon AST ProSAS-60 Navy BMS
3D Sub-bottom Imaging Sonar	Sonar that illuminates a broad swath of the seabed using a line array of acoustic projectors while acoustic backscattering from the illuminated sediment volume is measured with a planar hydrophone array.	Known systems are still experimental, currently demonstrated detection capabilities show very consistent detections through 30 cm of sand. Classification capabilities are unknown.	**High:** BOSS generates images of objects buried in underwater sediments.	Medium to high	EdgeTech BOSS

Lidar

Airborne Lidar Bathymetry has seen significant reduction in weight and increased resolution capabilities (point density) recently. Commercial systems can now be used on Unmanned Aerial Vehicles. Systems have been utilized to identify pipes (15cm) on the seabed, which makes this technology potentially useful for identifying larger munitions. Bathymetric Lidar can be used in relatively clear shallow water areas.

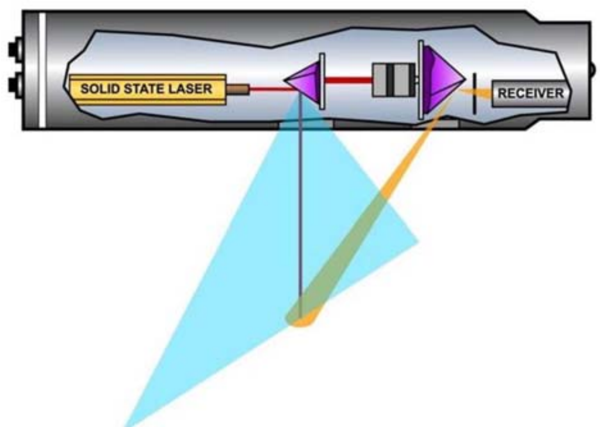


Figure 5-13: Laser Line Scanner Concept

Table 5-4. Laser Line Scan Resolution

WATER CLARITY	EXAMPLE	TYPICAL HEIGHT ABOVE SEAFLOOR	MAXIMUM SWATH WIDTH	RESOLUTION (PIXEL SIZE)
Very Clear	Hawaii	45 m	65 m	3 cm
Clear	San Diego	22 m	30 m	1.5 cm
Moderate	Washington State Massachusetts Bay	9 m	13 m	0.6 cm
Poor	Boston Harbor	3 m	4 m	0.2 cm

Magnetometers and Electromagnetic Induction

The most challenging investigations may require accurately determining the position of one or more submerged anomalies, and typically, the conditions in the underwater environment (e.g., silt or sand, wave and current action) support burial of munitions or their deep penetration. While high frequency sonar and laser line scanners can be used to detect surface anomalies in the underwater environment, and low frequency mine hunting sonars have the capability to detect items below the water-sediment interface, alternate technologies are available to detect buried metallic anomalies. Magnetometers and EMI are two technologies that can detect and map ferrous metal items (and non-ferrous metal items with EMI) in the subsurface. Details regarding these two technologies are presented in Section 4.2.1. Unlike typical conditions on land, conditions in the underwater environment (e.g., wave and current action) can continue to result in movement of the subsurface anomalies. Any required removal of underwater munitions should be considered soon after completion of the geophysical survey if there is potential for the survey data to become invalid.

For magnetometers and EMI, there is fall off in signal strength as the distance between the sensor and the target increases (the inverse cube of the distance for magnetometers and the inverse sixth power for EMI); therefore, the sensor must be near the sediment water interface (i.e., bottom) to accurately detect deep into the sediments. Orientation of the anomaly and background noise will also affect performance. For magnetometers and EMI, vertical orientation of the long axis of the item is the more favorable orientation for detection. Magnetometers are sensitive to iron-bearing minerals that may be contained in the seafloor. As this background signal increases, the distance at which an object can be detected will decrease.

Magnetometers and EMI detectors are available in many forms for use at underwater MRSs, including underwater and surface towed arrays, hand-held instruments used by divers, sled-mounted/vessel systems, and aerial systems. The Navy has a laser scalar gradiometer that it uses on its AUV to detect and classify targets. The CSM should be evaluated to determine which type of magnetometer/EMI device is best suited for the site-specific conditions. Surveys of shallow water areas may be efficiently completed with an aerial system, where deeper water environments may require use of an underwater towed array or a AUV mounted laser scalar gradiometer. Areas with thick vegetation for rough underwater topography may require a diver using a hand-held device. Table 5-5 presents a comparison of magnetometers and EMI technologies and example systems for each.

5.2.3 Anomaly Detection Platforms

Use of the anomaly detection technologies discussed in Section 5.2.2 must be associated with a platform for collection of measurements in the underwater environments. Types of platforms available include:

- man-portable,
- ROVs,
- AUVs, and
- vessels, with or without towed array systems.

Man-Portable Platform

The man-portable platform includes the use of divers to conduct surveys with hand-held detection systems. This option is most effective for the detection and removal of smaller, discrete items in localized survey areas. This option provides for high maneuverability within tight areas and also allows for visual investigation and identification of the anomalies as they are detected. However, the man-portable platform results in a very slow production rate that is dependent on such factors as wave action and current and exposes the divers to the hazard.

Two common search methods used by divers are the jackstay search method and the circle-line search method. An underwater jackstay search is a procedure conducted by divers swimming along a search line - the jackstay. An example of how this is conducted is shown in Figure 5-14. In the jackstay search method, the diver swims down the lower right buoy line, then swims to the opposite buoy line along a search line, looking 2 ft either side. The diver then moves the line

Table 5-5. Example Magnetometer and EMI Technology Comparison

TECHNOLOGY	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COST	REPRESENTATIVE SYSTEMS	ADDITIONAL INFORMATION
Magnetometers	A measuring instrument used to measure the strength or direction of a magnetic field.	**High:** Proven technology with high industry familiarization. Needs to be close to the seafloor to be effective. Detects ferrous objects only and unable to distinguish between MEC and other ferrous metals. Severely oxidized steel is not strongly magnetic. Can be configured as gradiometers to increase detection of ferrous items using horizontal, vertical, lateral and analytic signal.	**High:** Portable, proven technology, able to survey large areas quickly; waterproof and rugged equipment; equipment is readily available; can be operated simultaneously with other equipment.	Low	Analog Systems: Schonstedt 52-CX Schonstedt 72-CX Foerster FEREX 4.032 Ebinger MAGNEX 120 LW Foerster Ferex 4.032 Vallon ES 1302D1 Digital Systems: Marine Magnetics Explorer Marine Magnetics SeaSpy Marine Magnetics SeaQuest Geometrics 881 NSWC PC Laser Scalar Gradiometer	Analog systems are not usually co-registered with navigational data. Digital output should be co-registered with navigational data.
EMI	Used to induce a pulsed magnetic field with a transmitter coil, which in turn causes a secondary magnetic field to emanate from nearby objects that have conductive properties.	**High:** Well suited for use in shallow underwater environments. Array platforms may be hard to control. Depth of detection can be increased minimally by increasing power output of system. Can detect small and large ferrous and non-ferrous items.	**High:** Portable, proven technology, able to survey large areas quickly; waterproofed and rugged equipment; equipment readily available; can be operated simultaneously with other equipment except magnetometers; in most circumstances, affected by geology significantly less than magnetometers.	Low	Analog Systems: Pulse 12 Pulse 10 Digital Systems: Geonics EM61-MK2 Geonics EM61-MK2-HP Ebinger UXES 700-series	Digital signal should be co-registered with navigational data. Detection depths are highly dependent on coil size and power.

(stationary method) or the buoy clump (walking method) 4 to 5 ft, then swims back to the first buoy line, repositions, and repeats the process.

In the circle-line search method, the diver swims down a buoy line and ties off a knotted line to clump. The diver swims in a circle holding each succeeding knot until reaching the end of the search line (Figure 5-15).

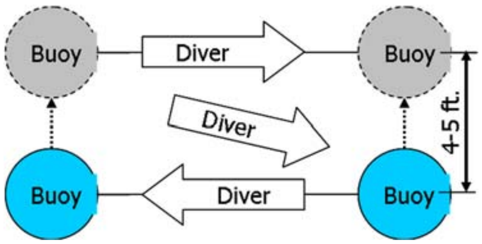


Figure 5-14. Jackstay Search Method

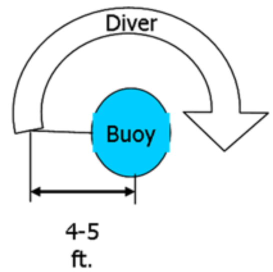


Figure 5-15. Circle Line Search Method

Anomalies detected using man-portable platforms must be marked so that they can be further evaluated and removed at a later date. Marking material may be as simple as weights with floats to mark the anomaly location and the use of underwater writing pads. Other options such as acoustic target transponders and sonar bells are also available. When selecting the appropriate marking option, consider that the battery life associated with the use of acoustic target transponders is approximately 1 to 18 months, whereas sonar bells will remain active for years. However, keep in mind that anomalies may move after being detected due to underwater conditions (e.g., waves and current action). Based on this, reacquisition and further investigation should be completed as soon as possible after identification.

Depending on the dive depths, additional requirements may apply if the man-portable platform is selected for the investigation. For example, when developing project budgets, note that diver wage premiums increase for deeper diving operations. Also, an on-site decompression chamber is required if the dive time requires decompression stops, or if operational depth is greater than 100 ft. Decompression chambers are expensive and should also be accounted for when planning and budgeting a project.

Remotely Operated Vehicles and Crawlers

A ROV is a tethered underwater robot. ROVs are unoccupied, highly maneuverable and operated remotely by a person. There are several classifications for ROVs, including micro, mini, observation, and work-class ROVs. They are linked to the ship by a tether, a group of cables that carry electrical power, video and data signals back and forth between the operator and the vehicle. The smaller ROVs are easily transportable and can be operated from piers and shore. The smaller ROVs however have more limited payloads. High power applications will often use hydraulics in addition to electrical cabling. They are capable of forming the platform for various identification technologies, including sonar, magnetometer, EMI, and video equipment. ROVs can also be equipped with a manipulator or cutting arm, water samplers, and instruments that measure water clarity, light penetration and temperature. Limitations of this option include reduced maneuverability due to the ROV tether, and also the tether acting as a source of drag in high current environments. An experienced operator is needed to control the ROV.

General positioning uses vessel-mounted GPS and a subsurface location technology. The types of location sensors include depth sensors, altimeters, cable counters, Smart Tether™ and/or acoustic ultra-short baseline (USBL) positioning system to track the position of the ROV in two- or three-dimensional space.

In specific circumstances where the conditions do not support an ROV, either lightweight or work-class, because of the depth, current, bottom type, marsh or swamp like conditions, or wave action, the ROV can be converted into a crawler. ROV crawlers have been used by the USACE to investigate MEC in salt marshes inaccessible by foot, boat or heavy equipment. In some cases, where the work-class ROV is involved, it is as simple as "bolting" on a set of caterpillar tracks to the underside of the ROV, like those shown in Figure 5-16, allowing it to operate in austere conditions. Special purpose ROVs already are permanently outfitted with tracks for operations in deep water environments. Lightweight ROVs have tracks on them that allow the ROV to be used for ship hull inspections, making them very maneuverable. The impact of the crawlers tracks on sensitive habitats as well as the potential for entanglement in a highly cluttered environment need to be considered.

Figure 5-16. Example ROV Crawler and Sled

Autonomous Surface and Underwater Vehicles

AUVs and ASVs are like robotic submarines or boats that travel underwater or topside without requiring input from an operator and are capable of carrying a wide array of payloads. AUVs and ASVs collect data using depth sensors, sonars, magnetometers, thermistors, optical, and chemical sensors while following a pre-planned route at speeds typically between 1 and 4 knots. They can range in size from centimeters to meters in length and are powered by rechargeable batteries. Monitoring and communication with the vehicle while underwater can be performed.

Since AUVs follow a pre-determined path for data collection, they are best suited for investigation of large areas with relatively easy underwater terrain and little vegetation. They do however have terrain following capability and obstacle avoidance sensors. They do not have any bulky, complex support equipment requirements, such as the tether for the ROV, to limit maneuverability. They can cover a large area in a relatively small amount of time compared to that of hand-held systems and ROVs that require operator direction, and so can be a cost-effective option for data collection if site-specific conditions are appropriate. Due to their relatively slow speed, AUVs can be affected by high current or surge environments like the nearshore.

Vessels

Vessels are the most used option as a platform for use of anomaly detection devices. They can be used with or without towed systems, making them suitable for a wide range of site conditions, including both shallow and deep water environments. The specific type of vessel selected for a site will be dependent on site-specific conditions. For example, shallow water conditions may include breaking waves and require vessels with less draft. However, smaller boats that have less draft are not as seaworthy as larger vessels and will be more prone to the effects of wind and waves. Figure 5-17 shows how various types of anomaly detection technologies can be attached to or towed by a vessel.

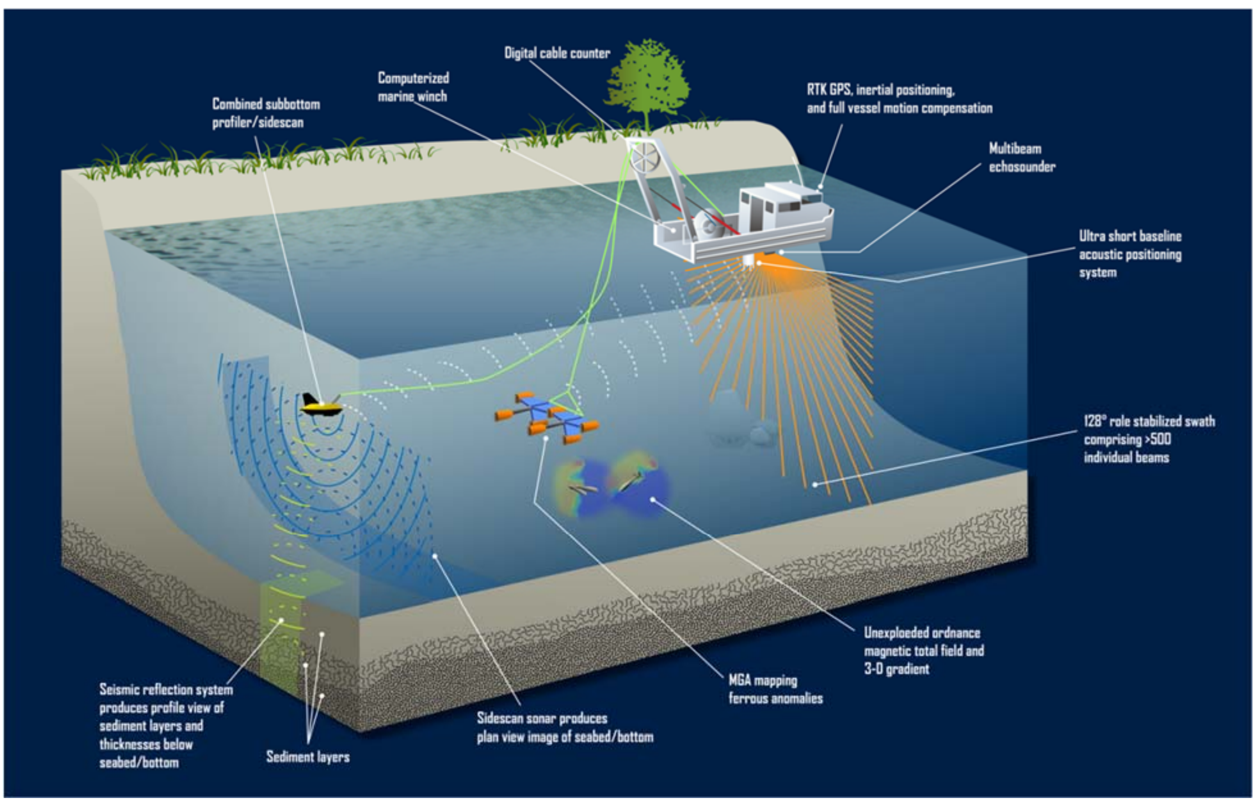


Figure 5-17. Example Vessel Platform with Associated Anomaly Detection Devices

Table 5-6 shows a comparison of the various platforms available, including man-portable, ROV, AUV, and vessels.

Table 5-6. Example Platform Comparison

PLATFORM	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COST
Diver	Diver uses a scuba set to breathe while performing an instrument-aided survey.	**High for small areas, Low for large areas:** Effective for the detection and removal of smaller, discrete items in localized survey areas.	**Medium:** Highly maneuverable and can operate in tight areas. Visually investigate and identify anomalies. Production rate is very slow and requires multiple divers due to safety considerations. Environmental factors (turbidity/temperature/currents) may impact implementability.	High for large area; Low for small area
ROV	A tethered underwater robot remotely operated by a highly skilled and trained human operator.	**Medium:** Effective for very short-range manipulator work as well as very long-range target detection. Slow production rate	**High:** Variety of sensors available and larger systems have manipulators that would allow investigation and remediation at the same time. Tether limits maneuverability and can act as a source of drag in high current environments. Experienced operator required. Surface power allows higher power sensor/manipulator packages.	High to low depending on size of system
AUV/ASV	A completely autonomous robotic submarine/vessel capable of carrying a wide range of sensors.	**High (Detection):** Effective for long-range surveying and detection. Does not have any bulky, complex support equipment requirements. Does not perform removal.	**High:** Autonomous predetermined survey pattern that doesn't require constant monitoring. Limited power supply for sensors and a limited sensor array. Decreased effectiveness in high current/surge/shallow water type of environment.	Medium
Vessel	Surface watercraft manned with skilled crew and equipment operators.	**Medium (Detection):** Wide range of sizes and capabilities. Available to survey from shallow to deep water with very long range target detection. Does not perform removal.	**High:** Can be outfitted with a wide variety of A-frames and davits for towed operations and equipment and sensors. Decreased effectiveness in high current/surge/shallow water type of environment. Obstacles or significantly uneven terrain may decrease sensor performance.	High

5.2.4 Navigation and Location

Navigation is the process of planning, recording, and controlling the movement of a craft. As mentioned previously, the most challenging aspect of underwater MRS investigations may be accurately determining the position of one or more submerged anomalies. It is important that the position of any identified anomalies be accurately recorded and tracked so that future investigation and reacquisition can be completed. Several navigation and location options are discussed below.

GPS with RTK control

Note that GPS doesn't work underwater, but that it can be part of underwater navigation solution. RTK is an approach for a precise GPS-based positioning system. In this approach, determination of range signal can be resolved to a precision of less than 10 cm (4 in). This is done by resolving the number of cycles in which the signal is transmitted and received by the receiver. This can be accomplished by using a combination of differential GPS correction data, transmitting GPS signal phase information and ambiguity resolution techniques via statistical tests—possibly with processing in real-time (real-time kinematic positioning, RTK). The GPS position is then combined with an additional underwater positioning system to determine the underwater location.

Ultrashort baseline (USBL) acoustic positioning

USBL is a method of underwater acoustic positioning. A complete USBL system consists of a transceiver, which is mounted on a pole under a ship, and a transponder/responder on the seafloor, a towfish, or on a ROV. A computer, or "topside unit", is used to calculate a position from the ranges and bearings measured by the transceiver. An acoustic pulse is transmitted by the transceiver and detected by the subsea transponder, which replies with its own acoustic pulse. This return pulse is detected by the shipboard transceiver. The time from the transmission of the initial acoustic pulse until the reply is detected is measured by the USBL system and is converted into a range.

To calculate a subsea position, the USBL calculates both a range and an angle from the transceiver to the subsea beacon. Angles are measured by the transceiver, which contains an array of transducers. The transceiver head normally contains three or more transducers separated by a baseline of 10 cm or less. A method called "phase-differencing" within this transducer array is used to calculate the angle to the subsea transponder.

USBLs have also begun to find use in "inverted" configurations, with the transceiver mounted on an AUV, and the transponder on the target. In this case, the "topside" processing happens inside the vehicle to allow it to locate the transponder for applications such as automatic docking and target tracking.

Long baseline (LBL) acoustic positioning

LBL systems are unique in that they use networks of sea-floor mounted baseline transponders as reference points for navigation. These are generally deployed around the perimeter of a work site. The LBL technique results in very high positioning accuracy and position stability that is independent of water depth. It is generally better than 1-meter and can reach a few centimeters accuracy. LBL systems are generally employed for precision underwater survey work where the accuracy or position stability of ship-based (SBL, USBL) positioning systems does not suffice.

Inertial Navigation System (INS) with DVL

INS is a navigation aid that uses a computer, motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculate via dead reckoning the position, orientation, and velocity (direction and speed of movement) of a moving object without the need for external references. It is used on vehicles such as ships, aircraft, submarines, guided missiles, and spacecraft.

DVLs bounces sound off the bottom (or a reference layer of water) and can determine the velocity vector of a subsea vehicle (or surface vessel) moving across the sea floor. This information can be combined with a starting fix, compass heading, and acceleration sensors (typically by use of a Kalman Filter) to calculate the position of the vehicle. DVLs are used to help navigate surface vessels, submarines, AUV, and ROVs for precise positioning in an environment where GPS, and other navigational aids, don't work. INS/DVLs collect, compile, and process velocity, heading, altitude, pitch and roll to determine position.

Tow cable lay-back

A tow cable lay-back uses an inclinometer to determine the tow cable position and is typically coupled with GPS and USBL to increase accuracy.

Smart Tether™

Smart Tether uses a series of embedded sensors nodes in the tether to determine position within 1.5 meters or better. These nodes use acceleration, magnetic, and rate-gyro sensors to measure the orientation and track the position of the tether and vehicle or diver. Data is transmitted to the computer screen/control box in real time.

Diver Navigation

Two commercially available advanced diver navigation systems include the Cobra-Tac and Shark Marine Navigator. The Cobra-Tac is a diver navigation instrument that operates autonomously without the need for acoustic baselines or floating-point buoys. The Cobra-Tac allows a diver to map bathymetry, navigate accurate grid patterns, mark and relocate anomalies, and survey the bottom using geodetic data points (e.g., GPS).

The Shark Marine Navigator is a diver guidance and sonar navigation system designed for hand-held operation in low visibility conditions. The system uses integrated BlueView multibeam sonar to provide divers with streaming sonar imagery of their surroundings. The instrument records time and dive duration, along with compass, depth, and temperature readings and determines position information from GPS and acoustic navigation systems. The capabilities of the Shark Marine Navigator make it a suitable tool for bathymetry profiling, diver guidance, and anomaly position identification.

Table 5-7 provides a comparative summary for some of these navigation and location options.

Table 5-7. Example Navigation/Location Comparison

NAV/LOC	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COST
GPS DGPS RTK GPS	Space-based satellite navigation system that provides location and time information.	**High:** Highly accurate to meter or decimeter or better accuracy but since the signal does not transmit underwater it is typically coupled with other technologies to increase overall accuracy. Rough sea surface can degrade accuracy.	**Med-High:** Widely available. Because satellite signals will not transmit underwater, it must be coupled with other devices.	Low
USBL	An acoustic pulse transmitted by a transponder (acoustically triggered) or responder (electrically triggered) sends out an acoustic pulse that the vessel mounted subsea hydrophone array measures for travel time and direction.	**High:** USBL does not require the setup of an array of beacons but is not as accurate as LBL. Increased accuracy with integrated GPS and INS. 0.2% of slant range achievable.	**High:** Easily implementable on surface vessels, ROVs, and AUVs but does require integration. High ship noise areas (harbors) can require a more accurate positioning system such as LBL. Decreased setup time and increased accuracy when systems contain integrated GPS and INS.	Low
LBL	An array of surveyed transponders which, through triangulation, determine the platform position.	**High:** Very high relative positioning accuracy (several cm to 1 m) and position stability that is independent of water depth.	**High:** LBL requires setup of an array of beacons and must be periodically repositioned. Rough terrain can reduce accuracy of LBL beacons due to influence of currents.	Med
INS with DVL	INS: Computers, accelerometers and gyroscopes used to continuously calculate sensor position, orientation, and velocity via dead reckoning. Greatly improved positioning when paired with DVL.	**High:** Precision degrades over time and distance requiring periodic correction. Improved accuracy possible through post processing.	**High:** Determines position of moving object without the need for external references. Can use USBL for periodic position correction. More accurate systems are “tactical grade” which are very costly but much more precise.	High
Towbody	Uses an inclinometer to determine position of tow cable.	**Low - High:** Inclinometer is typically coupled with GPS and USBL to increase accuracy.	**High:** Inclinometers are easily operated.	High

5.3 RI Data Collection

Once the transect design is prepared and the anomaly detection technologies and platforms have been selected based on the project objectives and site-specific conditions identified in the CSM, then the RI data collection phase can begin. RI data collection consists of several steps, including:

- Grid layout,

- Surface removal,
- GSV,
- Seafloor survey and data collection,
- Data processing, analysis, and anomaly selection,
- Anomaly reacquisition and investigation, and
- MEC/MPPEH management.

5.3.1 Survey and Grid Layout

The purpose of the survey and grid layout is to divide an area of concern into a series of grids for follow-on work. A map is prepared showing the location of each grid/waypoint, with DGPS coordinates for each corner so that they can be identified in the field. The survey team then locates these grid corners and places underwater markers at these locations. A naming or numbering convention should be established for the grid, and each marker identified accordingly. In the case of using an AUV, the vehicle would periodically surface to maintain accuracy of the GPS/mapping system and these locations would then define the survey lanes.

Personnel typically involved in this activity include a trained GIS manager, DGPS trained field technicians, and UXO-qualified technician to provide anomaly avoidance support during intrusive activity (i.e., marker placement). Depending on the site conditions and type of marker used, divers may be required for placement of the markers. Typical equipment and material required for the grid layout include DGPS equipment, metal detectors, markers, and lane lines/ropes. AUVs require a trained operator/mission programmer and depending upon the size of the AUV, personnel to help with launch and recovery the AUV. Additional personnel and equipment maybe necessary depending upon the platform used (i.e. vessel and crew).

5.3.2 Surface Removal

Surface removal is generally accomplished by a UXO dive master and a team of UXO dive technicians identifying metallic items with a metal detector. The items are marked for subsequent removal, or removed immediately using hand tools. Navigational tools are required for the divers to ensure adequate coverage of the grid area, and underwater ultrasonic two-way radios are used for communication between team members. Any MEC identified at the surface during surface removal activities should be managed accordingly. During the RI, it is anticipated that a small quantity of MEC will be recovered at the surface, and the MEC/MPPEH must be managed as the explosive items they are. It is also anticipated that surface removals will not be performed to as great an extent as on land during or before the RI due to the cost of performing the underwater removal.

5.3.3 Geophysical System Verification

The purpose of the GSV process is to ensure proper function and response of the geophysical survey instrumentation and may change depending upon the sensor used. The GSV process includes a daily equipment checkout using an IVS. The IVS consists of a reasonable number of objects in a line with the locations of the objects known to the sensor operator. In principle, the objects used in the IVS can consist of any well-characterized object (i.e., a “surrogate item”). However, objects of similar size and shape to common munitions are recommended such as pipe nipples. The process of developing an underwater GSV is still in development. Project teams will have to consider options for deployment to minimize cost, potential loss of surrogate items due to sinking into the subsurface and movement and to ensure consistent reacquisition in the proper orientation. Some considerations include attaching the items to wide bases to minimize sinking, attaching multiple items in series and marking with a transponder, and using round objects to get consistent signatures that do not rely on orientation.

Noise strips are also used in the GSV process. A noise strip is a strip containing no discrete anomalies or non-representative terrain or geology that will affect the instrument. The noise strip should be located near the IVS and is used to check that the noise level of the instrument is what would be expected for that site and that system noise is consistent day to day. For daily instrument checks, data would be collected in one direction down the center of the IVS and in one pass over the noise strip. The main objective of the daily run is to check that the sensor remains consistent as predicted and that the system noise levels have not changed, which would indicate an equipment malfunction.

A production blind seeding program is also as part of the GSV. Blind seeding provides on-going quality monitoring of data collection and the target selection process. It ensures that repeatable, consistent signals are obtained for calibration and performance validation. Blind seeds are available in similar size and shape to common munitions. Blind seeds are typically performed at a rate of 1/unit of production per day. Project teams need to have upfront discussions on the potential mobility of seed items and how their mobility will impact data validation.

The UXO QC Specialist is the primary personnel responsible for designing and installing IVS and also emplacing blind seeds. Equipment needs include the blind seed and IVS objects as well some means to emplace them in the sediment or seafloor and a suitable positioning and navigation system to mark the locations. Underwater IVS and blind seed tests should account for mobility, sinking in sediment, and other site-specific conditions.

Currently QA activities are being conducted utilizing a third party contractor or with remote equipment (underwater camera) on site by Navy personnel. Due to the logistics and restrictions on civilian navy personnel ability to conduct diving operations, much of the QA to date has been conducted through on site observations during work activities. Underwater QA/QC is an area where the techniques are evolving to demonstrate meeting the performance objectives.

5.3.4 Survey and Data Collection

The purpose of the survey and data collection phase of the RI is to detect and locate anomalies located within the underwater MRS. Several anomaly detection methods and platforms for their use were presented in Sections 5.2.2 and 5.2.3. As discussed in these sections, the appropriate technology should be selected based on data requirements needed to meet the project objectives and the site-specific conditions present at the underwater MRS.

Project scientists/geophysicists and data acquisition specialists, including divers and equipment operation experts, are involved during the data collection phase of work. The survey platforms, instrumentation, and data recording devices, along with positioning and navigation equipment is used to detect, mark, and record the location of anomalies encountered so that they can be further investigated and removed in the future.

5.3.5 Data Processing, Analysis, and Anomaly Selection

Once the survey data are collected, it must be processed and analyzed so that detected anomalies can be selected for reacquisition. For analog systems such as hand-held magnetometers and EM systems, the UXO technician uses instrument audio response to determine relative size and location of the anomaly. Therefore, anomaly selection is subjective and operator dependent.

When DGM systems are used, a geophysicist selects anomalies based on one or more of the following characteristics:

- Peak response over all channels
- Spatial extent of signal above background (signal-to-noise ratio)
- Estimated target depth, time constant and related decay-curve characteristics, shape parameters, location of anomaly center, and weight.

Digital data can also be evaluated using commercially-available software packages. An example of this software is the IVS 3D Fledermaus software suite. This software performs interactive three-dimensional geospatial data processing and analysis. A variety of software bundles are available, depending on the required data analysis, for example a standardized platform for data corrections and processing for multi-beam and swath sonars; a bundle for route planning; or a bundle for monitoring locations of vessels, AUVs, ROVs, and divers. It also provides for optional workflow to ARCGIS.

Data from the Navy systems such as the Small Synthetic Aperture Minehunter is processed by personnel at Naval Surface Warfare Center, Panama City Division. An excerpt of the data is generated that produces a target/anomaly list.

Targets/anomalies selected by the survey operator, geophysicist, and/or by the data processing software/analyst are then placed on the “dive list”. A “dive list” is a ranking of targets/anomalies for further investigation and possible removal.

5.3.6 Anomaly Reacquisition and Investigation

Anomaly reacquisition and investigation involves a diver first reacquiring the target/anomaly within the documented PQO location criteria. Search patterns such as those in figures 5-14 and 5-15 are used to reacquire the target. A diver then uncovers the target/anomaly if necessary and documents the item orientation and photographs the item if water clarity permits. Finally, the diver confirms MEC/MPPEH identify and condition. Positioning and navigation equipment are required to identify the predetermined location of the target/anomaly and data recording devices are used. Geophysical survey instruments (digital and/or analog) or imaging sonars can be used to reacquire the target/anomaly. Excavation tools are also used to uncover the target/anomaly.

5.3.7 MEC/MPPEH Management

During the RI, a small quantity of MEC and MPPEH will be recovered. MEC recovered during the RI is managed as MPPEH and is categorized as MDEH or MDAS. The quantity of MEC recovered will depend on anomaly density and percentage of the grid which was investigated. Excavated MEC/MPPEH items cannot be returned to the sea and must be managed as the explosive items they are. The MEC is normally destroyed in place or at least on site. Treatment is typically accomplished by:

- BIP
- Consolidated Detonation
- BIP with bubble curtain
- Water jet/bandsaw cutting
- Cap/encapsulation.

Further details regarding these destruction options and how to evaluate them are included in the in Sections 6 and 7.

5.4 Underwater Hazard and Risk Assessment

This section discusses the HHRA and ERA considerations for underwater MC.

5.4.1 Underwater MC Sampling and Ecological Risk

The fate and transport of MC and ecological receptors present at underwater MRSs are very different from those associated with a terrestrial site. Underwater sites can vary in terms of environmental settings and safety. Underwater MEC is typically found as UXO and DMM. They can usually be found scattered across the seafloor on sediment surfaces, buried in sediments, or encased with biological growth. If the MEC casings are not immediately cracked or breached, it can take many years to corrode or breach before they begin to leach MC. Underwater mobility of MEC casings can potentially cause breaching through physical collusions with other hard substrates (e.g., rocks, coral, metallic debris).

When the MEC remains relatively intact, pinhole cracks can develop and expand into larger voids over time due to corrosion and release MC into the underwater environment. Corrosion is an electrochemical process requiring three components: 1) regions of opposite polarity (i.e., an anode and a cathode), 2) an electrolyte, and 3) a metallic return path completing the electrical circuit

Once an underwater MEC casing is breached, the leachates of the MC can be in the following form but not limited to:

- HMX (cyclotetramethylene-tetranitramine);
- RDX (cyclotrimethylene-trinitramine);
- Perchlorate;
- Metals (e.g., lead, arsenic, aluminum, manganese);
- TNT (2,4,6-trinitrotoluene) and several TNT transformation products:
    - 2-ADNT (2-Amino-4,6-dinitrotoluene);
    - 4-ADNT (4-amino-2,6-dinitrotoluene);
    - 2,4-DANT (2,4-diamino-6-nitrotoluene);
    - 2,6-DANT (2,6-diamino-4-nitrotoluene);
    - 2,4-DNT (2,4-dinitrotoluene);
    - 2,6-DNT (2,6-dinitrotoluene);
    - TNB (trinitrobenzene);
    - DNB (dinitrobenzene).

Once a breach hole is developed, the fate and transport modeling shows that predicted TNT concentrations are on the order of nanograms per liter (ng/L) in the vicinity of the release locations for a single test shell. This provides the basis for an order of magnitude estimate for worst-case scenarios. For example, to generate TNT concentrations to the micrograms per liter (ug/L) level in the water column, it would take one thousand shells of the same shell integrity to be co-located at a single site. [44]

Currently, laboratory investigations have shown that TNT has limited persistence in the environment. TNT binds readily with sediments, but also degrades rapidly in sediment. Sediment microorganisms are also capable of degrading both RDX and HMX. RDX degrades rapidly in sediments and HMX mineralizes in sediments. This rapid degradation results in TNT and RDX approaching steady concentrations much lower than maximum attainable concentrations. Based on laboratory results, TNT, RDX and HMX are also low in toxicity and do not bioaccumulate. However, it should be pointed out that laboratory exposures cannot be achieved in a natural environment because of the fate and lower/undetectable concentrations of the MC and the ocean water, circulation, dilution and sedimentation characteristics of marine waters.

Based on these multiple lines of evidence, environmental risks associated with energetic fill are likely negligible. Field investigations highlight the fact that if MC is detected, it is most likely to be found in close proximity of the breached MEC casing. The concentrations, if any, would greatly decrease further beyond the breached MEC shell casing. A study of note using polar organic chemical integrative samplers (POCIS) was conducted to assess exposure to MC and results indicate MC concentrations are at extremely low levels. [45][46][47]

Several site-specific studies also support the above points regarding ecological risks associated with MC. The Isla de Vieques Bombing Range, Vieques, Puerto Rico, Mariana Islands Range, Pacific Ocean, and Hawaii's Ordnance Reef were subject to ecological and human health risk assessments by an independent agency, the Agency for Toxic Substances and Disease Registry (ATSDR). This agency conducted human risk assessments from human consumption of local seafood species sampled by EPA at Vieques and by NOAA at Ordnance Reef (Figure 18). The EPA and NOAA collected tissue samples in Vieques waters. ATSDR public health assessments concluded that seafood consumed from these waters did not constitute a human health risk. NOAA also conducted random sampling activities of Vieques and Ordnance Reef sediments and coral tissue. The similar sampling results concluded that there were no detectable MC levels at these locations as well.

Additional sediment and fish tissue data were collected at the former Naval Ammunitions Depot, currently the Jackson Park Housing Complex, which serves the Bremerton Naval Complex, Washington. Similar conclusions were obtained with non-detectable MC at this site. The Army and NOAA collected sediment and tissue data from Hawaii Ordnance Reef where DMM was found. Again, similar results were obtained with undetectable MC. Sediment and water column data obtained from sampling MCAS Cherry Point, North Carolina. Offshore bombing targets, BT-9 and BT-11, also resulted in non-detectable MC.

Figure 5-18. Sampling at Ordnance Reef, HI
(Photo courtesy of U.S. Army)

It should be noted that while underwater energetic MC sampling yields non detects, metals are found in detectable quantities. Detectable metals may be potentially associated with the metallic MEC casings degradation. But naturally occurring and non-site related anthropogenic metal sources may also contribute to underwater metal concentrations. In Vieques, lobsters are found with arsenic in their tissues. This is a result from bioaccumulation of naturally occurring arsenic. Another example of this includes the Hawaiian Ordnance Reef site where detectable metals sources were located at the outfall from the on-shore Wai'anae Wastewater Treatment Plant (WWTP) and attributed to natural land drainage from adjacent road surfaces and volcanic rock minerals. Both of these examples support the conclusion that metal contamination was not the result of underwater munitions.

The laboratory and field R&D database and the sampling trend for nondetectable MC at multiple MRP and FUDS sites confirms low ecological and human health risk trends. These results support decreased confirmatory MRS sampling in lieu of extensive, costly and unnecessary sampling.

5.4.2 Hazard Assessment

The CERCLA response process includes the development of site-specific risk assessments appropriate to the requirements of a site. The results of the risk assessment help site managers decide whether further response action is required, and support the risk management decisions that are made throughout the remedy evaluation, selection, and implementation process. For sites with MEC/MPPEH, the same response process is used, but a risk assessment is called a hazard assessment to address the unique explosive hazard posed by the MEC/MPPEH. In some cases, the optimum hazard management path may be to leave the MEC/MPPEH item in place. A safety- and environmental hazard-driven assessment needs to be done to evaluate the best path forward. Benefits from MEC/MPPEH removal have to be weighed along with the potential safety hazards and environmental impacts of the removal process itself. While tools to assess the risks posed by MCs below an explosive hazard in sediments have been developed, there is no methodology designed to address explosive safety and environmental hazards at underwater sites. In order to make a hazard assessment and management decision, underwater sites will have to develop a MEC/MPPEH hazard assessment model to addresses the following factors:

- Accessibility – the likelihood that a receptor will be able to come in contact with a MEC/MPPEH item
- Sensitivity – the likelihood that a receptor will be able to interact with a MEC/MPPEH item such that it will detonate
- Severity – the potential consequences of the effect (e.g., death, injury) on a receptor should a MEC/MPPEH item detonate

The evaluation of these factors will determine if a response action is required and where that response action should be conducted.

5.4.2.1 UXO Mobility Model

While there is no MEC hazard assessment model, the UXO Mobility Model is a tool that can be used to predict the mobility of underwater items to determine if the item can move to the point of exposure. A good indicator of the mobility is where it has been found and performing an analysis of the site history of where it may have been originally deposited.

The model can be run in three different modes, with costs and site specific data requirements increasing with each mode. The UXO mobility model user's manual [48] includes a description and required input per mode as follows:

- Mode 1 - When little more than the general coastal setting and the time frame of MEC introduction and initial depth are known
- Mode 2 - When information is known about the gross site specific details of a suspected MEC field
- Mode 3 – When site-specific contemporary, high resolution information is known about the MEC field.

The mobility analysis and the initialization of the model is based on a set of simplifying assumptions that maximizes the risk and represents a worst-case scenario. An estimate is made of the extent of offshore waters from which UXO can reach the beach in the future, referred to as the critical zone. The model simulations are conducted over a 20-year period, and the probabilities of occurrence reported are for a 20-year simulation.

Due to the costs to setup and run the UXO Mobility Model and some of the uncertainties associated with the model, SERDP/ESTCP is currently funding several research projects to improve the mobility analysis.

6.0 MEC/MPPEH REMOVAL AND TREATMENT TECHNOLOGIES

The purpose of the FS is to develop and evaluate potential remedies that permanently and significantly reduce the threat to public health, welfare, and the environment; select a cost-effective remedial action alternative that mitigates the threat(s); and achieve consensus among DON, EPA, state, and local authorities regarding the selected response action. This chapter describes response and process options specifically applicable to terrestrial and underwater MRSs, and discusses other considerations including MPPEH management.

6.1 Terrestrial MEC/MPPEH Removal and Treatment

Once terrestrial anomalies are identified, selected, and reacquired, they may be intrusively investigated using the following strategies:

- Hand excavation (using a backhoe to dig alongside the anomaly no closer than 12 inches, with final excavation by hand is still considered hand excavation)
- Mechanical excavation (using commonly available digging equipment such as backhoes and excavators)
- Mass excavation (generally using armored digging equipment)
- Remotely operated excavation (commonly available digging equipment that has been modified for remote operation).

Following excavation, soil and MEC may be further processed using sifting, mechanized sorting, and magnetically assisted recovery. Table 6-1 summarizes the commonly used excavation and processing strategies for intrusive investigation and removal of MEC.

During anomaly investigation, an EZ is established to ensure control of access by non-essential personnel and to protect against exposure to unintentional (or intentional) detonations. DDESB-approved ECs can be used to minimize the size of the EZ, as described in DDESB TP-16 (latest revision). DDESB TP-16 includes the necessary calculators and instructions for calculating EZs. In some instances, evacuation of surrounding communities may be necessary, and any evacuation is coordinated directly with local and/or state officials.

6.1.1 MEC and MPPEH Management

The management of MEC and MPPEH is governed by the ESS. An ESS is the document that details how the explosives safety standards in OP5 Volume 1 [1] are applied to munitions responses. The ESS also details how the project will comply with the applicable environmental requirements related to the management of MEC and MPPEH. At an MRS where an ESS is required, no site operations can begin unless NOSSA has reviewed and endorsed and the DDESB has reviewed and approved the ESS. An ESS is required whenever there is to be intentional physical contact with MEC or MPPEH. An RI will normally require an ESS because getting estimates of the amount of metal and MEC/MPPEH and its distribution both laterally and depth wise are important for evaluating alternatives in the FS. The ESS is prepared by the UXO contractor and on most MRSs on-site destruction of the MEC is planned for and performed.

Table 6-1. Example Comparison of Terrestrial Excavation/Processing Technologies

TECHNOLOGY	DETECTION	EFFECTIVENESS	IMPLEMENTABILITY	COST	REPRESENTATIVE SYSTEMS	NOTES
Hand excavation	Hand excavation consists of digging individual anomalies using commonly available hand tools	**Medium:** It can be very thorough and provides good data on any munitions collected.	**High:** Can be accomplished in almost any terrain and climate. Is limited only by the number of people available.	**Average:** Is the standard by which all others are measured.	Probe, trowel, shovel, pick axe.	Are locally available and easily replaced tools.
Mechanized removal of individual anomalies	This method uses commonly available mechanical excavating equipment, such as a backhoe or excavator.	**Medium:** Used in conjunction with hand excavation when soil is so hard it causes time delays. Method works well for the excavation of single anomalies or larger areas of heavy ferrous metal concentration.	**High:** Equipment can be rented almost anywhere and is easy to operate. Allows excavation of anomalies in hard soil and clearing of large areas with substantial metal concentration.	**Low:** In hard soil this method has a lower cost than that of having the single anomalies hand excavated.	Tracked mini-excavator, bull dozers, loaders, etc.; multiple manufacturers.	Equipment is easy to rent and to operate.
Mass excavation and sifting	Armored excavation and transportation is earth moving equipment that has been armored to protect the operator and equipment from unintentional detonation.	**High:** Process works very well in areas of heavy concentration of UXO or DMM. Can separate several different sizes of material, allowing for large quantities soil to be returned with minimal screening for MEC.	**Medium:** Earth moving equipment is readily available. However, armoring is not as widely available. Equipment is harder to maintain and may require trained heavy equipment operators. Not feasible for large explosively configured munitions.	**High:** Earth moving equipment is expensive to rent and insure and has the added expense of high maintenance cost.	**Earth moving equipment:** Many brands of heavy earth moving equipment, including excavators, off-road dump trucks, and front-end loaders, are available. **Sifting equipment:** Trommel, shaker, rotary screen from varying manufacturers.	Can be rented, armor installed, and delivered almost anywhere. Significant maintenance costs.
Mechanized soil processing	Once the soil has been excavated and transported to the processing area, it is then processed through a series of screening devices and conveyors to produce segregated soils of different grain sizes.	**High:** Mechanized processing systems are a proven technology for removing MEC and other solid materials from soil.	**High:** Equipment and references for planning and operations are readily available.	**Medium-High:** Acquisition and operation of these systems is initially expensive, though savings may be realized for large economy of scale efforts.	A wide variety of equipment and suppliers are available for shaker and trammel systems.	Use of magnetic technology (rollers) can augment capabilities for some MEC applications.
Magnetically assisted recover	The most promising application of magnetic technology is in scrap and soil processing.	**Low:** Primarily used in conjunction with mass excavation and sifting operations. Can help remove metal from separated soils, but does not work well enough to eliminate the need to inspect the small size soil spoils. Magnetic systems are also potentially useful to help with surface clearance of fragmentation and surface debris.	**High:** Magnetic rollers are easily obtained from the sifting equipment distributors and are designed to work with their equipment.	**Low:** This method adds very little cost to the already expensive sifting operation.	Magnetic rollers and magnetic pick-ups are available from many manufacturers of the sifting equipment noted above.	Installed by sifting equipment owners.
Remotely operated removal equipment	Remotely operated equipment is excavating equipment that has had additional control equipment added that allows the equipment to be operated remotely.	**Low:** Remotely operated equipment reduces productivity and capability of the equipment. Method is not widely used and is not yet proven to be an efficient means of MEC recovery.	**Low:** Uses earth moving equipment, both mini-excavator type and heavier off-road earth moving equipment. Machinery is rigged with hydraulic or electrical controls to be operated remotely.	**High:** Has a combined cost of the base equipment plus the remote operating equipment and an operator. Remote operation protects the operator, but can create high equipment damage costs.	Many tracked excavators, dozers, loaders, and other equipment types have been outfitted with robotic remote controls.	EOD robots are almost exclusively used for military and law enforcement reconnaissance and render-safe operations. They have been tested for MEC applications.

Material excavated during intrusive investigation is typically classified immediately by the UXO technician as either munitions-related or non-munitions related. If it is munitions related it qualifies as MPPEH. If MPPEH, it is immediately evaluated for being MEC (e.g., UXO or DMM).

MEC recovered during intrusive investigations is normally either destroyed in place or at the very least, onsite. Destruction is typically accomplished by:

- Open detonation – BIP
- Open Detonation - consolidated detonations
-

Open detonation is the open-air explosive destruction of MEC using an explosive donor charge to initiate the detonation to safely remove the explosive hazard. There are two types of open detonation, BIP and consolidated detonations. These two methods are the most commonly used methods to safely remove the explosive hazard.

Munitions which are identified as not safe to move must be destroyed in place. BIP is the destruction of any MEC by detonating the item without moving it from the location where it was found. The standard procedure for a BIP is to countercharge the munitions using donor explosives.

Munitions that are identified as safe to move can be destroyed by consolidating the MEC. Consolidated detonation is the destruction of any MEC by detonating the items at a location other than where they were found to remove the explosive hazard. It is only for MEC that have been inspected and deemed acceptable or safe to move by the SUXOS and UXOSO. MEC that is safe to move can also be combined with MEC that cannot safely be moved to perform a consolidated detonation. Figure 6-1 illustrates a BIP, a consolidated detonation where all of the MEC was safe to move, and a consolidated detonation where safe to move MEC was combined with unsafe to move MEC.

In some instances, where standard ECs (e.g., sandbags, separation, etc.) cannot provide sufficient protection from intentional detonation or where stakeholders may be particularly sensitive to disposal operations, munitions can be destroyed in a CDC. The CDC technology is significantly limited regarding availability. Any considerations for use of the CDC should be discussed with NAVFAC HQ due to the inefficiency and cost of the system.

In the CDC, MEC is placed inside a specially constructed chamber and detonated. Virtually all sound, all fragmentation and all other effects of the detonation are contained within the chamber. Further, the chamber can be configured with an exhaust system which scrubs the

Figure 6-1. Photos of BIP, and Consolidated Detonations
(Photos courtesy of U.S. Navy)

gasses generated by the detonation before they are released into the atmosphere. The CDC has a limited NEW, which restricts the overall amount of explosives that can be detonated in the chamber whether as an individual munition or per detonation event (e.g., multiple small items). Smaller CDCs are transportable but have a lower NEW than they are approved to destroy. Current transportable models can contain detonations up to 40 lb NEW. MEC must be determined safe to move to use a CDC. Air handling and filtration may be required depending on the munitions being detonated. The secondary waste streams of pea gravel, filter dust, and decontamination water must be characterized and disposed of properly.

Laser initiation uses portable, vehicle-mounted lasers to destroy MEC. They are used from a safe distance to heat MEC laying on the surface, resulting in high- or low-order detonation of the MEC. Laser systems do not require donor charges. However, low-order detonations result in a release of MC that must be managed. These systems have not been used at MRS but have been used in the wars in Iraq and Afghanistan by the U.S. military.

Munitions which may be moved can either be placed in temporary storage for a regularly scheduled disposal operation, or may be consolidated into a single disposal operation (consolidated detonation). Munitions determined safe to move by the SUXOS and UXOSO must be documented as such, in writing.

The donor explosives used for any of the disposal methods are typically brought to the site by the production contractor and stored in an approved temporary magazine that is sited and secured in accordance with the ESS. At some sites, the contractor is able to exercise just-in-time delivery of donor explosives, precluding the siting of magazines and storage of donor explosives on site. Donor explosives and MEC/MPPEH cannot be stored in the same magazine. Therefore, on many sites, at least two portable magazines are necessary. Guidance for storage of explosives and MPPEH is contained in OP5 Volume 1 [1] and their handling must be included in the ESS.

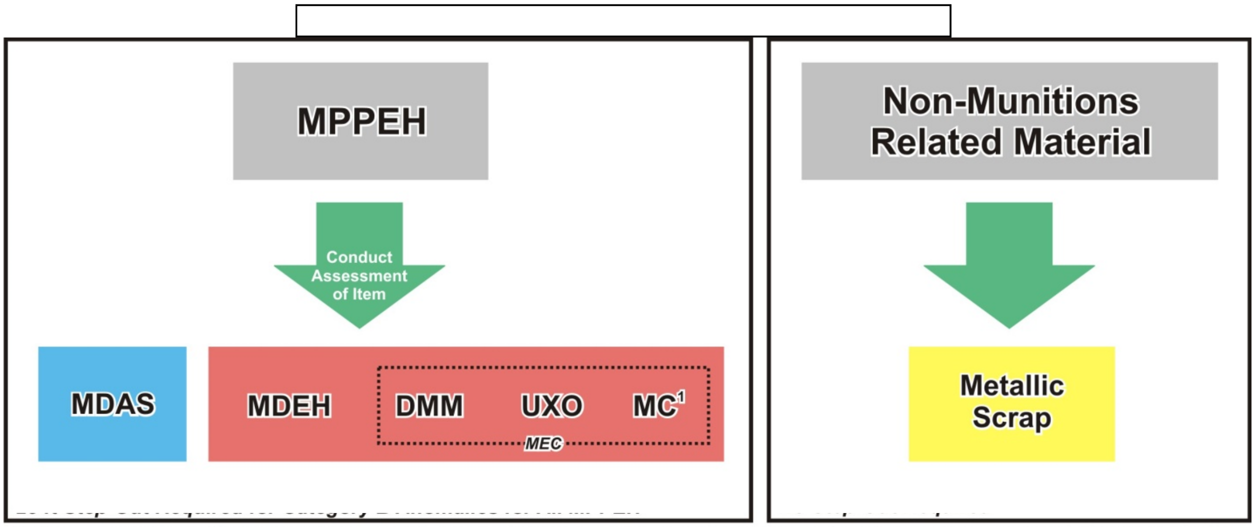
Material categorized as MPPEH, but not MEC, requires additional assessment and documentation (formerly inspection and certification) to determine whether it is to be categorized as MDEH or MDAS. Figure 6-2 shows the relationship and categorization scheme for material excavated during intrusive investigations.

Classifying MPPEH as MDEH is typically used only when on-site detonation is not an option and items must be transported off-site for final disposition to a qualified receiver.

Demilitarization is the act of eliminating the functional capabilities and/or inherent military design features from DoD property. DOD 4160.28 and OP5 require that MDAS be demilitarized before release from DoD control. Demilitarization removes the capability for reuse, meets trade security requirements, and removes the "military look-alike" appearance.
Shredding/crushing may be applied to debris to remove its military characteristics, and maybe combined with other processes such as chemical or thermal treatment that eliminate explosives residues from the debris. Shredders and crushers can render small arms, fuzes, and other components inoperable by mechanical action, but must meet explosives safety standards. One system is a hydraulic-powered shredder mounted on a roll-off platform, suitable for on-site waste reduction and materials processing. The roll-off system features a transportable, self-powered shredder that is powered by a diesel motor. A folding conveyor discharges the shredded material into a waste container.

Shearing operations with hydraulic shears have proved to be a safe, effective means of demilitarizing concrete-filled practice bombs. Shearing opens and mutilates the casing, thus satisfying demilitarization requirements. Shearing also separates the steel from the concrete so both components can be readily recycled.

Table 6-2 summarizes the common methods of destroying and decontaminating MEC and MEC debris during the terrestrial RI and which are options to be evaluated in the FS.



(1) Corresponds to MC present in high enough concentrations to pose an explosive hazard; step-outs will be conducted if MC is clearly visible to a UXO tech during intrusive investigation.

MPPEH - Material Potentially Presenting an Explosive Hazard
MDAS - Material Documented as Safe
MDEH - Material Documented as an Explosive Hazard
MC - Munitions Constituents

DMM - Discarded Military Munition
UXO - Unexploded Ordnance
MEC - Munitions and Explosives of Concern

Figure 6-2. MPPEH Categorization Scheme

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Table 6-2. Example Comparison of Terrestrial Treatment/Decontamination Technologies

TECHNOLOGY	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COST	REPRESENTATIVE SYSTEMS	NOTES
			Treatment of MEC			
BIP	BIP is the destruction of MEC for which the risk of movement beyond the immediate vicinity of discovery is not considered acceptable. Normally, this is accomplished by placing an explosive charge alongside the item.	**High:** Munitions are individually or collectively destroyed with the destruction verified (QC/QA).	**Medium-High:** Uses field-proven techniques, transportable tools and equipment and is suited to most environments. Public exposure can limit viability of this option. ECs can further improve implementation. Exclusion zones are required which can impact implementability	**Low:** Is manpower intensive. Costs increase in areas of higher population densities or where public access must be monitored/controlled.	Electric demolition procedures; nonelectric demolition procedures	Disposition of resultant waste streams must be addressed in planning. Any stream produced by BIP is not contained. Increased regulatory involvement may result in higher life cycle cost for waste (for characterization, treatment, and disposal) than for technologies that do contain the waste streams. The DoD has committed to reducing its reliance on the use of OD.
Consolidated detonations	Consolidated detonations are defined as the collection, configuration, and subsequent destruction by explosive detonation of MEC for which the risk of movement has been determined to be acceptable either within a current working sector or at an established demolition ground.	**High:** Techniques recently developed and refined in Iraq are providing documented successes. Use of donor munitions is also proving effective. Is limited in use to munitions that are "safe to move."	**Medium-High:** Generally employs same techniques, tools, and equipment as BIP. Requires larger area and greater controls. Most EC not completely effective/applicable for these operations.	**Medium:** Is manpower intensive; may require material handling equipment for large-scale operations.	Electric demolition procedures; nonelectric demolition procedures; forklifts and cranes	Disposition of resultant waste streams must be addressed. Increased areas require additional access and safety considerations. Waste streams produced by consolidated detonations are not contained. As regulatory agencies become more involved in munitions responses, this may yield higher life cycle costs for waste (for characterization, treatment, and disposal) than for technologies that do contain waste streams. This could be of even greater concern in consolidated detonation operations where there will be more residual generated and, thus, potentially greater concentrations of regulated analytes.
Laser initiation	Portable (vehicle-mounted) lasers are used from a safe distance to heat MEC laying on the surface, resulting in high- or low-order detonation of the munitions.	**Low-Medium:** Is still in development, though currently is deployed in Iraq for testing. Tests show positive results for 81 mm and smaller munitions, with reported success on munitions up to 155 mm. Produces low-order type effect; subsequent debris still requires disposition.	**Low-Medium:** MEC targets must be exposed/on surface for attack by directed beam. GATOR Laser System (diode laser neutralization via fiber-optic delivered energy) does not require line-of-sight within approximately 100m. GATOR system does require approach and placement of fiber-optic cable at appropriate position of MEC. Laser systems are still addressing power, configuration, transportability, and logistics issues.	**Low-Medium:** Requires greatly reduced manpower. Has added equipment, transportability, and logistics concerns. No explosives are required by the system.	ZEUS-HLONS GATOR LASER	Offers added safety through significant standoff (up to 300m). (Note: Acceptable safety standoffs must be evaluated for specific MEC and scenarios.) ZEUS prototype was deployed in Afghanistan (2003). Waste streams produced by laser initiation are not contained. As regulatory agencies become more involved in munitions responses, this may yield higher life cycle costs for waste (for characterization, treatment, and disposal) than technologies that do contain waste streams. This may be of even more concern with laser initiated detonation/deflagration, as residual contamination may be higher than with traditional BIP. Low-order detonations could generate environmental contamination
			Treatment of MEC			
CDC stationary	CDCs involve destruction of certain types of munitions in a chamber, vessel, or facility designed and constructed specifically for the purpose of containing blast and fragments. CDCs can only be employed for munitions for which the risk of movement has been determined acceptable.	**High:** Chambers successfully contain hazardous components. Current literature review shows containment up to 40 pounds (lb) (net explosives weight [NEW]).	**Low-Medium:** Stationary facilities typically must meet regulatory and construction standard for permanent/semi-permanent waste disposal facilities. Service life and maintenance are issues. Such facilities are not commonly used in support of munitions responses. Produces additional hazardous waste streams.	**High:** Sitting and construction required. Low feed rates lead to more hours on site. Significant requirements for system maintenance.	Typically is designed on case-by-case basis.	System cleaning and maintenance usually require personal protective equipment (PPE) and worker training. Have probable permitting issues with employment of technology.

Table 6-2. Example Comparison of Terrestrial Disposal/Decontamination Technologies (Continued)

TECHNOLOGY	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COST	REPRESENTATIVE SYSTEMS	NOTES
CDCs-mobile	CDCs involve destruction of certain munitions in a chamber, vessel, or facility designed and constructed specifically for the purpose of containing blast and fragments. CDCs can only be employed for munitions for which the risk of movement has been determined acceptable for transport over public highways.	**High:** Chambers successfully contain hazardous components. Current literature review shows containment up to 40 lb NEW.	**Medium-High:** Designed to be deployed at the MRS. Has greatly reduced footprint compared to stationary facilities. Service life and maintenance are issues. Requires additional handling of MEC. Produces additional hazardous waste streams.	**Medium-High:** Possible construction required (e.g., berms, pads). Low feed rate leads to more hours on site. Significant requirements for system maintenance.	Transportable Detonation Chambers (T-10) Kobe Blast Chamber	System cleaning and maintenance usually require PPE and worker training. Have possible permitting issues with employment of technology (on other than CERCLA/FUDS sites). The fact that the waste stream is contained and is more easily dealt with (even when hazardous) is an advantage in terms of public perception and in life cycle cost.
Treatment of Munitions Debris						
Chemical decontamination	Such decontamination should only be used when there is a requirement to eliminate all explosives residues from munitions or range-related debris.	**Low-Medium:** Great variety of chemicals. Can be difficult to test for effective treatment. May generate additional waste streams (some hazardous).	**Low:** Requires containment of multiple hazardous materials. May require emissions controls. Worker training and PPE typically required. No mobile systems deployable to MRS exist. National Defense Center for Energy and Environment is working on a mobile system, but it only treats scrap metal, not MEC.	**High:** Requires specialized manpower, containment requirements, and additional waste stream processing.	Supercritical water oxidation Photocatalysis Molten salt oxidation	
Thermal treatment	Decontamination is achieved by exposing the debris to high temperatures (between 600 and 1400 degrees Fahrenheit) for specified periods of time.	**High:** Methods are proven means of attaining high degrees (five times) of decontamination.	**Medium:** Typically stationary; however, mobile processes exist. Service life and maintenance are issues. May have low feed rates due to safety concerns. Produces additional hazardous waste streams.	**High:** Possible construction required. Low feed rates lead to more hours on site. Requires greater maintenance of system.	Rotary kiln incinerator Explosive waste incinerator Transportable flashing furnace.	System cleaning and maintenance usually require PPE and worker training. May require permit to deploy.
Shredders and crushers	These technologies use large machines to deform metal components. This results in unusable remnants and overall reduced volume of scrap.	**Medium** Shredders are mostly used to render inert munitions debris unrecognizable as munitions. Very limited use to date to shred MEC. Shredding MEC presents heightened probability of accidental detonation. Residue typically still requires additional treatment to achieve higher decontamination levels.	**Low-Medium** Typically are stationary facilities. Very high maintenance is expected.	**Medium-High:** Requires specialized equipment and operators. Has high maintenance. Requires additional waste stream processing.	Shred Tech ST-100H Roll-Off (vehicle mounted)	Disposition of resultant waste streams must be addressed.

6.2 Underwater MEC/MPPEH Removal and Treatment

6.2.1 MEC Evaluation and Recovery

Once anomalies are detected at underwater MRSs, they must be further evaluated so that a positive identification of a munition and its configuration, including fuzed state, can be made. Diver inspection is the simplest and most versatile method as it puts a trained expert in direct proximity of the item of interest. If there are discrete items of interest at a shallow depth on or near the bottom (not buried below the reach of the diver's arm), divers may be the most effective approach. However, if there are numerous items of interest in deeper water, the effectiveness of divers decreases. In these cases, ROVs may be the more cost-effective option. ROV inspections sacrifice some agility around the target but benefit from significantly reduced personnel risk and the ability to operate around the clock. When a munition has been positively identified, a decision must be made regarding whether it will be removed and disposed, disposed in place, or left in place. Because every site is unique, removal operations are also unique, often posing different challenges that must be addressed. Some site characteristics to consider include the number and type of munitions, the munitions configuration (i.e., whether the munitions are fuzed and armed), the munitions condition (e.g., deteriorated, encrusted by sea life, buried in full or part), geologic characteristics of the sea floor (sandy, rocky, etc.), operational environment (the water's depth, visibility, wave action, currents, wind), and the need to protect the marine habitat and threatened or endangered species. These characteristics drive site-specific operational requirements for recovery technology, as well as the safety considerations for people and the environment.

Several types of evaluation and recovery technologies for MEC can be employed at a site, including divers, lift bags/baskets, robotics/ROVs, magnetic lift systems, and dredging and screening. Each of these technologies is discussed further below. Conducting operations underwater using these technologies is significantly more expensive than analogous operations on land. Efficiency in the rate of production is decreased in comparison to terrestrial operations, with an increased potential to leave MEC items behind.

Divers

Evaluation and recovery by divers can be augmented with a variety of tools, including hand tools and air lift equipment.

An air lift is another type of excavation tool that can be used underwater by a diver. It consists of an air compressor, length of pipe, basket, valve, and hose. The technology is simple and easy to use. Compressed air is injected into a pipe and the buoyancy of the air creates a vacuum that lifts water sediment through the pipe. It is most effective at depths below 15 ft due to the creation of the vacuum effect. Larger size materials such as cobbles can jam in the pipe.

Lift Bags/Baskets

Lift bags and baskets lift munitions using the buoyant force created by an inflated bag. Use of this equipment requires rigging of the bag to the MEC being recovered or placement of the MEC into a basket rigged with a lift bag. Figure 6-3 is a lift bag photo. This is a simple and effective technology, but also requires the use of a dive team. As with any recovery technology, the item must first be determined safe for removal.

Figure 6-3. Photo of Lift Bag
(Photo courtesy of SubSalve)

ROVs/Robotic Recovery

The DoD emphasizes the use of ROVs and robotics because, as a rule, their use greatly increases safety and operations can normally proceed around the clock. ROVs and other robotic technologies equipped with manipulators can perform recovery tasks in deep water or areas considered too hazardous for dive teams. This may include, for example, picking up and placing MEC items into a basket deployed with a lift bag and then engaging the lift bag for removal of the MEC. Only a few demonstrations have been performed using either ROVs or Robotic Recovery. At one demonstration underwater project, two 500 lb practice munitions were successfully removed from a 30 ft depth using a Robotic Recovery.

As mentioned previously, use of an ROV or other robotics reduces agility around the target, but also significantly reduces personnel risk and provides the option of full-time (24 hr) operation. Other factors to consider are the limited number of suppliers available for this equipment, high capital costs required, additional support vessels and equipment required for large ROVs, and limitations on the size of objects that can be removed. Additionally, removal is not always possible due to encrustation and other factors.

Magnetic Lift Systems

Magnetic lift systems can be an effective technology for ferrous MEC removal in shallow underwater areas if the MEC is not heavily encased in mineral deposits or marine growth. Magnetic lifts can recover single MEC items in shallow water that may be buried too deeply in the sediment layer to be recovered by a diver with hand tools. System components include the spud, recovery shroud, dredge assembly, TV camera, and electromagnets.

One example of this technology is the Magnetic UXO Recovery System (MURS). It is an automated ordnance excavator equipped with remote operation. The MURS consists of a Caterpillar 325L hydraulic excavator with 25 ft boom, electromagnet, power source, and claw to facilitate extraction. It can reach digging depths of up to 15 ft. During an underwater test (shallow 4 ft water depth) with inert ordnance, the MURS successfully recovered a 500 lb bomb, 81 mm mortar, GATOR mine, and 105 mm HEAT projectile [49]. The type of bottom needs to be considered when applying this technology because some bottom types will make removal extremely difficult (e.g., muddy bottoms.)

MEC Dredging

Various types of dredging can be used for recovery of MEC at underwater MRSs. The primary forms of dredging include mechanical and hydraulic, each of which have several process options for implementation. Tables 6-2 and 6-3 summarize information related to the implementation of hydraulic and mechanical dredging, respectively.

Issues related to the dredging of MEC include the five Rs:

- Removal accuracy and precision
- Resuspension
- Releases
- Residuals
- Risk/Hazard

Dredging equipment must be equipped with highly accurate GPS or other navigational devices to maximize removal accuracy and precision. Mechanical dredging is limited by the reach of the equipment (boom or cabling length and design), and common depths for implementation of hydraulic dredging are in the range of 40 to 50 ft. Large debris can also interfere with the effectiveness of dredging, particularly with hydraulic dredging.

The disturbance created during dredging activities can result in increased turbidity of the water column and subsequent resuspension of the sediment material. Silt curtains can be used to contain suspended sediments within the work area, minimizing adverse effects of these releases on the surrounding environment. An important consideration is whether there are other chemicals in the sediment that can impact the environment by being re-suspended, such as metals from anti-fouling paint. There is also an extreme impact to the local benthic community in the immediate area of dredging where sediments are removed.

Residuals that require handling, after dredging operations to recover MEC are complete, include the dredged sediment and water from dewatering operations. The schedule of dredging operations is also controlled by restricted dredging windows to minimize impacts to the surrounding ecological receptors, such as fish and birds.

Dredging screens can be used in conjunction with dredging operations for two purposes: to leave behind MEC in the dredged area, or to remove MEC from the dredge material. In the case of buried MEC, an intake screen may be used to leave behind the MEC for further evaluation before determining whether or not the object should be removed. This protects both the dredge operators and the receiver of the dredge spoils. A screen can also be used after the dredge spoils are removed to separate the MEC objects for subsequent treatment.

Table 6-3 and Table 6-4 summarize information on hydraulic and mechanical dredging. Table 6-5 presents a comparison of the evaluation and removal options presented in this section, divers, lift bags, ROVs/robotics, magnetic lift systems and dredging.

Table 6-3. Hydraulic Dredging

DREDGE TYPE	EXCAVATION METHOD	REMOVAL METHOD	TRANSPORT METHOD	PLACEMENT METHOD
Hopper	Hydraulic suction, hydraulic erosion, mechanical dislodgement using knives or blades	From bottom to dredge vessel in hydraulic pipeline as a sediment water slurry	Sediment settles in hopper; vessel moves to placement site	Bottom discharge or pump out
Cutterhead	Mechanical dislodgement using rotary cutter, hydraulic suction, hydraulic erosion	From bottom to dredge vessel in hydraulic pipeline as a sediment water slurry	From dredge vessel to placement site or barge in pipeline as a sediment-water slurry	Direct discharge on land, water, or beneficial use site
Dustpan	Direction suction, impingement scour using water	Same as above	Same as above	Same as above

Table 6-4. Mechanical Dredging

DREDGE TYPE	EXCAVATION METHOD	REMOVAL METHOD	TRANSPORT METHOD	PLACEMENT METHOD
Bucket	Mechanical dislodgement, scooping with bucket	Wire rope with clamshell or dragline	Barge, land-based conveyor belt, trucks; material may be side casted	Bottom discharge, pump out, or mechanically to unload; direct discharge from belt, truck, or bucket
Backhoe	Mechanical dislodgement, scooping with backhoe bucket	Rigid structural members with backhoe bucket	Same as above	Same as above

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Table 6-5. Example Recovery Comparison

PLATFORM	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COST
Diver	Diver uses hand tools to perform recovery of MPPEH/MEC.	**Medium:** Effective for the removal of smaller, discrete items in localized survey areas. Effectiveness can diminish with depth and turbidity.	**High:** Highly maneuverable and can operate in tight areas. Visually investigate, identify and recover anomalies. Production rate is very slow and requires multiple divers due to safety considerations.	**Medium:** $10K/day/dive team
ROV	A tethered underwater robot/vehicle remotely operated by a highly skilled and trained human operator.	**Medium:** Effective for very short-range manipulator work, although hourly production rates may be lower than divers. Able to operate 24/7 well as very long-range target detection.	**Medium:** Variety of sensors available on larger systems that have manipulators that allow remediation. Tether limits maneuverability and can act as a source of drag in high current environments. Experienced operator required and larger support vessel to support larger ROV used for recovery increases cost. Increased safety due to remote operation.	**High:** high capital (up to $1M) mobilization (up to $100K), and operation and maintenance (O&M) costs ($900K to $1M/month)
Robotics	A tethered underwater robot remotely operated by a highly skilled and trained human operator.	**Medium:** Effective for very short-range grapple work although hourly production rates may be lower than divers. Able to operate 24/7. Requires repositioning.	**Medium:** Easy to mobilize to jobsite, but requires more effort than ROV to move within work area. Limited number of suppliers. Increased safety due to remote operation.	**High:** High capital (up to $20M) and O&M costs (up to $1.9M/month)
Magnetic lift	Electromagnet crane/winch with control system.	**Low:** Effective for the removal of smaller, discrete items in localized shallow water (~20 ft) survey areas. Bottom type can affect performance	**Low:** Demonstrated at pilot scale and with one commercial system. Requires accurate remote positioning and near direct contact with MEC/MPPEH. Increased safety due to remote operation.	**High:** Costs TBD, estimated to be high
Dredging	Dredging is an excavation activity in shallow seas or fresh water areas with the purpose of gathering up bottom sediments and disposing of them at a different location.	**High:** Effective for the subsurface removal of large areas with a high density of items. Requires additional screening to remove MPPEH/MEC with can limit effectiveness.	**Medium:** Subjects items to a high amount of energy. Limited number of suppliers. Extreme impact to local benthic community. Temporary impact to water quality due to suspended sediments.	**Very High:** Mobilization (from $1M to $8M); O&M (from $0.35 to $20/cy)

6.2.2 Underwater MEC Treatment

In order to determine treatment options, the type of MEC must first be identified - UXO (fuzed and armed) or DMM (unfuzed and unarmed). Options for treatment of these MEC objects include BIP (high order), BIP (high order) with bubble curtain, BIP (low order), consolidated detonation, abrasive water jet cutting, encapsulation, and capping.

High Order BIP

BIP is detonation of MEC in place. Selection of this option should be based on safety considerations associated with removal of the object and also the hazards associated with MECdetonation. The hazards associated with BIP include overpressure (i.e., shockwaves) and blasting effects (i.e., noise). These effects can be mitigated by planning appropriate EZs to keep workers at a safe distance or through the use of ECs such as bubble curtains. Bubble curtains however are not as effective with larger munitions containing higher amounts of net explosive weight and the larger munitions will still have a significant impact on the local environment from the overpressure. Directions for developing underwater EZs can be found in NOSSAINST 8020.15 (Series)/MCO 8020.10, which provides minimum safe separation distances for underwater unintentional detonations during munitions response operations. In planning for these mitigation measures, sympathetic detonation, or the detonation of other nearby MEC, should be considered.

Underwater noise recording equipment is deployable at ranges to monitor and measure noise in and around offshore activities such as BIP treatment. Collection of noise measurements can support noise analysis for estimating source level and frequency content of underwater noise baseline as compared to activity implementation (e.g., blasting and dredging). It can also support modeling of underwater sound propagation for species of marine mammal, fish and human divers.

Bubble curtains are a mitigation technology to augment BIP treatment. They are designed to reduce pressure waves and noise from UXO BIPs in order to protect marine life, and they are required by NMFS to mitigate offshore oil platform demolitions and underwater pile driving. The Navy has developed a successful research and development prototype bubble curtain (Figure 6-4) for large MEC which can be deployed by divers in water up to 30 ft depth. The system is comprised of individual lightweight sections (~65 lb in air) with segments of perforated tubes welded into assemblies to effectively provide three parallel rows of bubble screen

Bubble curtains limit the area of environmental impact from BIP and are simple to implement. However, they are not effective in shallow restricted water due to reverberation and small space available.

Another BIP mitigation technology being developed is blast mats, or covers. Research and development of underwater blasting mats is currently on-going. The blasting mats are meant to mitigate sound pressure levels, blast overpressure, and fragmentation of the MEC. They consist of a wire mesh design, and are ideal for use in shallow waters near populated areas and in conjunction with bubble curtains.

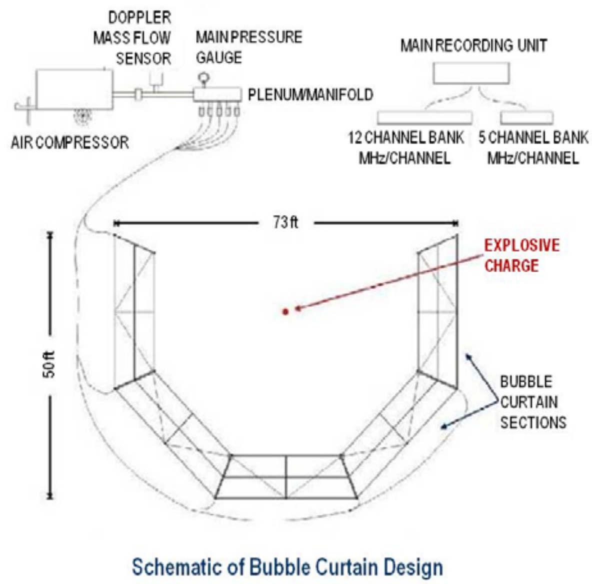

Figure 6-4. Example Bubble Curtain Design
(Graphic courtesy of ESTCP)

Additional ecological impacts must also be considered when implementing BIP. For example, in some cases, it may be appropriate to use smaller initial charges to scare away sea life before implementing the main charge. It should be recognized that there will be a localized impact to the environment from detonation; however, high order BIPs are chemically very efficient reactions and will not result in significant releases of MC into the environment.

Low Order BIP

The use of low order BIP treatment mitigates the acute blast effects experienced with high order BIP. Low order BIP involves a small donor charge to rupture an ordnance shell to initiate a partial energetic reaction of high explosive filler in the ordnance (Figure 6-5). In some cases, it may be more economical to low-order MEC in place rather than moving it to a separate disposal site. Considerations include the local environmental conditions at the site (presence of sensitive habitats, endangered or protected species, recreational uses of the area, etc.), the size and nature of the MEC (UXO or DMM), and distances involved. The major disadvantage to low-order detonation is that it may create a waste stream and release MC into the environment. However, limited ecological toxicity and fate data does support that underwater MC does not pose an ecological risk. The release of MC into the environment may be a better option than an unmitigated detonation that would certainly harm marine life.

Figure 6-5. MK 82 Low Order Detonation

Monitor in Place

At some sites, MEC may become less accessible naturally through coral encrustation and sedimentation. In many cases, it is safer to allow MEC to remain in place if natural processes are occurring, rather than attempting to extract the MEC object from its surroundings. Dredges have been modified to leave MEC in place during dredging operations to prevent exposure to the MEC in the spoils or to the crew operating the dredge. Some areas have natural sedimentation buildup that doesn't allow for effective detection of the MEC due to depth and can also serve as a barrier to prevent exposure. Encrustation can also make attempts at removal difficult, if not impossible. The Remotely Operated Underwater Ordnance Recovery System demonstration encountered numerous MEC that could not be removed with the systems manipulators (Overall recovery of 80 of the 218 items identified for removal). Photos of MEC that have been encrusted with biogrowth are shown in Figure 6-6.

Water Jet Cutting
Water jet cutting is a tool capable of slicing into metal using a jet of water at high velocity and pressure, or a mixture of water and an abrasive substance. Once the object is cut, explosives and propellants from within the shell can be removed and disposed of safely. This method is ideal for cutting materials that are sensitive to high temperatures, as the fluid used for cutting also cools the object. Debris from the cutting process must be contained, but implementing this option allows the shell to be left in place in cases where removal of the object may be too hazardous. The oil and gas industry has used underwater water jet cutting systems for many years and has developed methods for cutting access holes that may be useful in MEC treatment.

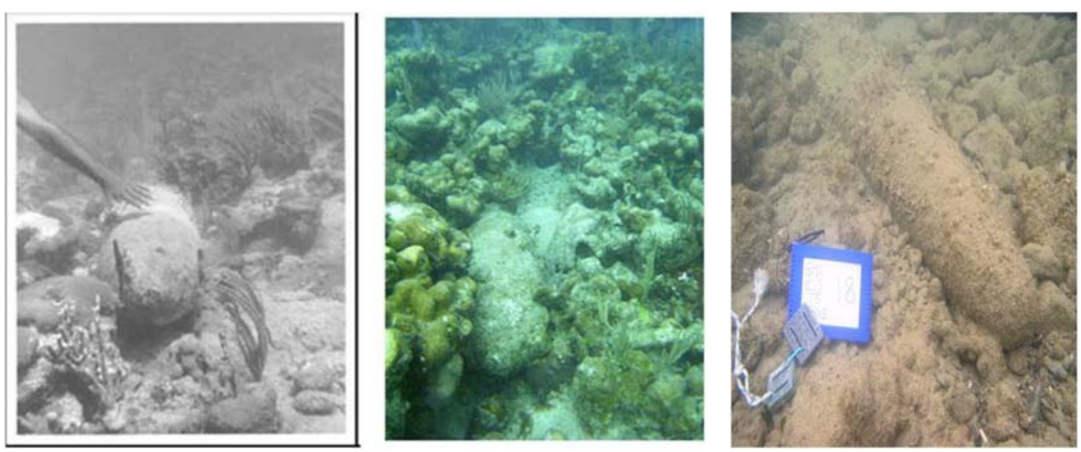

Figure 6-6. Photos of Natural MEC Encrustation
(Photos courtesy of U.S. Army and U.S. Navy)

Bandsaw Cutting
Bandsaw cutting is an alternative method for cutting MEC to remove the explosives and propellants from within the shell that is performed topside. The bandsaw blade is constructed of a continuous band of metal with teeth along one edge to cut. Bandsawing produces uniform cutting action as a result of an evenly distributed tooth load. This technology was developed for use in Cambodia and used as part of the Ordnance Reef demonstration project. In the Ordnance Reef demonstration project, robotics was used to remotely cut recovered munitions and expose

the explosive constituents so that it could be treated thermally in a radiant/convection batch oven. This technology can also be used for terrestrial sites.

Capping

Traditionally, capping has been used as a technology to manage contaminated sediments by isolating the contaminated sediment with capping material and thereby eliminating contact with the contaminants. For some COCs, reactive caps have been designed. The reactive material is part of the cap to treat contaminants in the sediment. The cap design is highly dependent on site-specific conditions. In calm waters a simple sand layer may be sufficient for capping, whereas sites with significant wave energy and/or tidal currents may require additional armoring of the cap material to keep it in place. Geotextile tubes, commonly referred to as GEOTUBES, may be used to encapsulate sediments and placed over the MEC item. Capping can also be an effective means of treating MEC that is difficult to recover. Isolating the MEC in place can effectively eliminate potential future exposure to the hazard. Capping normally requires maintenance to ensure that the cap is still effectively managing the hazard.

Table 6-6 provides an example summary comparison of the available MEC treatment technologies.

6.2.3 Technology Research and Development

The latest in underwater munitions research and development technology can be tracked through SERDP-ESTCP. SERDP and ESTCP are the DoD's environmental research programs. The programs respond to environmental technology requirements that are common to all of the military services, complementing the services' research programs. SERDP and ESTCP promote partnerships and collaboration among academia, industry, the military services, and other Federal agencies. RPMs are encouraged to take advantage of technology demonstrations at underwater MRSs. Technology demonstrations provide free data and reports in exchange for using the site for the demonstration. Involvement in such programs also has the added benefit of helping to facilitate communication and trust with project stakeholders.

The Navy's Environmental Sustainability Development to Integration (NESDI) program is sponsored by the CNO Environmental Readiness Division (N45) and managed by NAVFAC. The principal objective of the NESDI program is to invest in innovations that enhance Fleet operational readiness. Some of the projects funded by the NESDI program that enhance Fleet operational readiness have an ancillary benefit to the MRP.

Systematically conducted, well-documented treatability studies are an important component of the RI/FS process under CERCLA. These studies provide valuable site-specific data necessary to aid in the screening, selection, and implementation of the site remedies and allow for the evaluation of new technologies such as the ones developed by SERDP, ESTCP and NESDI. Contact your FEC Munitions Response Workgroup member to get in contact with these organizations.

Table 6-6. Example MEC Treatment Comparison

TREATMENT	DESCRIPTION	EFFECTIVENESS	IMPLEMENTABILITY	COST
BIP (high order)	Method used to destroy MPPEH/MEC, by use of explosives, in the location the item is encountered cuing the detonation to go high order.	**Medium:** Effective for the treatment of discrete items in localized survey areas. Can result in ecological damage and may cause other items in area to sympathetically detonate.	**High:** Implementable in areas with enough space to allow for explosives safety measure. May require the use of smaller initial charges to scare away birds, fish and mammals.	**Low:** $350/shot (does not include dive ops or mitigation costs)
BIP (high order) with Bubble Curtain	BIP using a ring of bubbles to attenuate the overpressure from a high order detonation.	**High:** Effective for smaller MPPEH/MEC. Reduced ecological damage and potential for sympathetic detonation compared to BIP.	**High:** Simple to implement. Not implementable for larger munitions and in small, confined areas due to reverberation.	**Medium:** Above costs, plus Bubble Curtain (TBD)
BIP (low order)	Method used to destroy MPPEH/MEC, by use of explosives, in the location the item is encountered causing the detonation to go low order and thus not consume all the energetic material.	**High:** Effective for MPPEH/MEC with a small chance for items to high order. Reduced short-term impacts to environment.	**Low:** Simple to implement. Has been used to protect cultural and natural resources from high order detonation impacts. Regulatory concern over residual MCs being left in the environment.	**Low:** $350/shot plus costs to collect and treat residue (does not include dive ops)
Monitor in Place	Munitions become encrusted and /or covered by sedimentation over time	**Medium:** Effective for the areas where access can be controlled or limited. No ecological damage from detonation	**Medium:** Simple to implement. Regulatory concern over MEC and residual MCs being left in the environment	**Medium:** Requires long term monitoring costs to be considered
Consolidated detonation ashore/afloat	Consolidation and BIP of multiple items at once after transfer to a barge or land.	**High:** Effective for the treatment of multiple items at once. Must be safe to move and results in increased ESQD arcs.	**High:** Minimal underwater environmental impact. Requires additional equipment (barge, etc.) and procedures to implement.	**Low:** $30/shot (does not include dive ops)
Water jet or bandsaw cutting	Remotely operated tool used to cut open and expose energetic filler for follow on treatment, usually thermally.	**High:** Effective for MPPEH/MEC. Production rates can be slow. Contains and treats MPPEH/MEC.	**High:** Minimal underwater environmental impact. Requires additional equipment (x-ray, barge, etc.) and procedures to implement.	**High:** TBD
Encapsulation and capping	A multilayered system of materials which are used to prevent exposure to MPPEH/MEC by covering the MPPEH/MEC.	**Medium:** Effective for difficult to recover or buried MPPEH/MEC. Requires long-term monitoring of effectiveness/integrity of cap.	**Medium:** Significant cost to implement. Extreme impact to local benthic community. Likely to encounter regulatory concern with MPPEH/MEC left in place.	**Very High:** $600K/acre

6.3 Land Use Controls

LUCs are physical, legal, and/or administrative mechanisms that restrict access and specific activities. LUCs are used primarily to manage risk/hazard during implementation of a remedy, as well as residual risk/hazard after completion of a remedy. Because some MEC might not be detected or removed during a remedial action, some form of LUC is then typically required at an MRS to account for residual hazard even if active removal/treatment is conducted. In some cases, interim LUCs that are implemented by a TCRA (pre-ROD) may be required to reduce exposure to the hazard. The DoD *Policy on Land Use Controls Associated with Environmental Restoration Activities* [50] provides additional information on LUCs. LUC mechanisms for MEC are typically of the following types:

- Physical controls – physical mechanisms that reduce or eliminate potential exposure to MEC, typically by limiting or prohibiting access or warning people of potential dangers. Fencing and signage are examples of physical controls. Physical controls are also known as ECs. Figure 6-7 provides examples of signage typical for an MRS.

Figure 6-7. Typical Signage at an MRS

- Legal controls – administrative mechanisms imposed primarily to ensure that legal restrictions on land use are implemented, monitored, and enforced. Restrictive covenants and deed restrictions are examples of legal controls. LUCs in the form of legal controls ensure that current and future land use is compatible with agreements within the project stakeholder team that form the basis for the evaluation, selection, and implementation of the remedy. Legal controls are also known as institutional controls (ICs). Figure 6-8 summarizes the typical ICs utilized at an MRS, and Figure 6-9 provides information regarding the relative strengths and weaknesses of these ICs.

At an MRS where the restriction of land use is a component of the remedy, the LUC must be clearly defined, coordinated amongst interested parties, and enforceable. At active bases, LUCs should be implemented through documentation in the Installation Master Plan/Regional Integrated Master Programs to prevent unintentional contact with MEC in the future. Implementing LUCs through standard real estate and land use management mechanisms helps to ensure that LUCs remain associated with the site even through property transfer.

LUCs are implemented when a site cannot support unrestricted use or unlimited exposure. However, when considering a remedial alternative for an MRS that includes LUCs, the

Category	IC	Description
Proprietary controls	Easement	An interest in a parcel entitling its holder to use or restrict use of land owned by another
	Restrictive covenant/deed restriction	Prohibits or restricts development, use, or construction on a parcel because of the presence of MEC/MC
	Reversionary interest	Similar to an easement, but with provision that if IC terms are violated property reverts back to owner
Local government controls	Zoning restriction	Method of locally controlling land use
	Permit program	Requirement to obtain permission
	Siting restriction	Limits land use subject to natural hazards
	Overlay zoning	Siting restrictions combined with zoning ordinances

Figure 6-8. ICs Typically Implemented at an MRS

IC	Strengths	Limitations
Easement	A legally binding control.	Relies on property owner compliance.
Restrictive covenants	Flexibility to apply to individual plot or area.	Hard to administer and subject to removal by courts.
Reversionary interest	Effectively used in the past.	Does not prevent inappropriate use of the property.
Zoning restriction	Derives LUCs from state/local law.	Often subject to amendments or revisions.
Permit program	Easy to implement, typically by single agency.	Requires effective administration to verify compliance.
Siting restriction	Can address very large areas with similar hazards.	Not always able to control inappropriate development.
Overlay zoning	See Zoning and Siting.	See Zoning and Siting.

Figure 6-9. Relative Strengths and Weaknesses of MRS ICs

unrestricted land use alternative (i.e., accomplishing a level of remediation that no longer requires controls) should also be considered, along with its associated costs and impacts to the environment per DoD policy.

It is DoD policy to consider the life-cycle costs of LUCs before implementation and for each component to maintain a LUC database. This requirement is fulfilled for the Navy and Marine Corps by the use of the LUC tracker (A component of NIRIS).

6.3.1 Underwater Use Controls

Underwater use controls include ECs and ICs designed to limit access to designated areas and exposure to MEC left in place at underwater MRSs. ECs can include fences along the shoreline, signs and warning buoys, guards and patrol boats, and caps. All of these engineered methods are design to limit access to MRSs where MEC remains in place so that potential exposure is minimized. Long-term monitoring and maintenance of ECs is required to ensure that they remain protective into the future.

ICs are legal devices imposed to ensure that ECs and/or restrictions on site use remain in place and are enforced. ICs can consist of notices to mariners, information in coast pilots, notices to navigation interests, markings on nautical charts, educational materials, permits/danger zones, etc. Figure 6-10 shows some examples of underwater use controls.

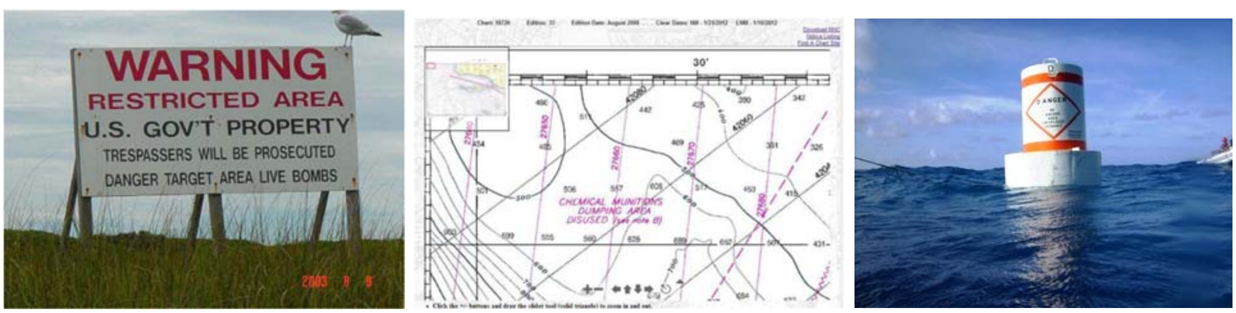

Figure 6-10. Example Underwater Use Controls

Provisions for the establishment of danger zones in navigable waters of the United States are included in 33 CFR Part 334. This part also includes descriptions of each danger zone that has been established.

6.3.2 Educational Materials

Educational materials are primarily concerned with MEC Safety, which can most effectively be achieved through robust education and outreach. A MEC Safety program should be designed to educate military personnel, civilians, and children about the potential hazards associated with MEC. The DENIX website (http://www.denix.osd.mil/uxo/) is intended to provide educational, training, and outreach resources for anyone potentially impacted by MEC as well as guidance on what to do should they encounter or suspect they have encountered MEC. Also, it serves to provide a consistent message (Recognize, Retreat, Report!) for use in local public involvement efforts. The website is a "toolkit" from which people and organizations can use individual "tools" to enhance or supplement local explosive safety programs. Educational material on terrestrial and underwater MEC safety is included on the website.

6.3.3 Long-term Management

Where the remedy for an MRS includes some level of LUCs, long-term management will be required. Long-term management is implemented by way of five-year reviews that assess the continued effectiveness of the remedy. Five-year reviews are specifically required by CERCLA. Reviews may be conducted at a frequency less than every five years if conditions at the MRS warrant (e.g., land use changes). It is important to consider the costs for long term management in the FS.

In addition, the long-term management phase may involve monitoring of soil, areas prone to erosion and exposure of MEC such as beaches or hillsides, frost heave, GW, and/or other media. Although GW is the most common media associated with long-term management, there may be other environmental media or site types that are subject to management to ensure the remedy remains protective, including sediment monitoring, landfill and disposal site gas monitoring, and ecological resources monitoring. Such long-term monitoring requires a site-specific plan, with the plan conforming to relevant and existing requirements and containing information associated with the number and types of samples, the required personnel and project management during monitoring, and the ultimate use of the data in the project decision-making framework.

The MRS project team should consult the NAVFAC ERB Web site for the latest guidance and policy related to issues pertaining to long-term management on ER Program sites.

6.4 MC Treatment Technologies

Residual MCs that are no longer an explosive hazard can still present an environmental concern requiring treatment. A variety of treatment technologies have been developed to date and are implemented to reduce amount of contaminated material at a site, remove the component of the waste that makes it hazardous, or immobilize the contaminant within the waste. However, different forms of energetic material and MCs require different technological approaches for their treatment and disposal.

Developed treatment technologies allow for decontamination of impacted soils and debris so that the MC is no longer an environmental concern. Bioremediation, predominantly in situ bioremediation and bioslurry methods, low thermal desorption and wet air oxidation are just a few examples of treatment technologies. Practical application of the specific technology is dependent on safety, logistics, throughput and cost associated with cleanup of the MC.

Treatment technologies for MC can be divided into:

- Physical/chemical treatment technologies including soil vapor extraction, solidification/stabilization, soil flushing, chemical oxidation, and electrokinetic separation.

- Biological treatment technologies include bioremediation, bioventing, phytoremediation, and monitored natural attenuation.

- Thermal treatment technologies include electrical resistivity heating, steam injection and extraction, conductive heating, radio-frequency heating, and vitrification.

Table 6-7 provides a general summary of the effectiveness of the in situ technologies for various contaminant classes. The main destructive technologies for MCs in soil include slurry phase bioreactors and constructed wetlands, hot gas decontamination, and advanced oxidation processes. GW extraction technologies include reverse osmosis, filtration and passive barrier treatment walls.

6.4.1 Physical/Chemical Degradation

Physical/chemical approaches consist of changing the chemical or physical state of the contaminant. This may be accomplished through volatilization (e.g. soil vapor extraction [SVE]), solubilization (e.g. surfactants) or chemical reactions (e.g. in situ chemical oxidation [ISCO], in situ chemical reduction [ISCR], solidification). These methods offer potential advantages to biological treatments because they are often faster, can treat highly contaminated environments. The goal of a chemical/physical approach is to transform the compound of interest into a less toxic compound (e.g. carbon dioxide and water) or, and mineral elements or structurally transform the parent compound into products that easier to recover (i.e., abiotic/biotic approach). This section provides a review of some of the more commonly used chemical and physical approaches for treating explosives-contaminated soil and water.

Chemical Reduction Using Zero Valent Iron (ZVI)

ZVI treatment of explosives-contaminated soil in static piles has occurred at the bench scale (70 kg). Comfort et al. [51] used contaminated soil containing RDX, TNT, and HMX from an outwash pond at Los Alamos National Laboratory and treated it with Fe0 and some acidifying amendments. ZVI effectively removed 98 % of the RDX and TNT within 120 days under static, unsaturated conditions [51].

Chemical Reduction Using Zero Valent Magnesium

Zero valent magnesium (ZVMg) utilizes magnesium, which has a very negative reduction potential (-2.37 V). This compound has been used to degrade a variety of persistent organic pollutants such as polychlorinated biphenyls (PCBs) and polybrominated diphenyl ether as well as the primary high explosive triacetone triperoxide [52].

Table 6-7. Summary of In Situ Treatment Technologies for MC

MC	Available Treatment Option	Advantages and Limitations of Treatment Technology
Munition impacted soil and debris	Wet air oxidation	- Treats slurries containing reactive and ignitable material. - Effective in treating RDX. - May produce hazardous byproducts that require further treatment.
MC impacted soil	Windrow composting	- Composting using naturally abundant microorganisms that utilize explosive compounds as source of energy. - Relatively long but highly effective with lower concentrations of MC. - May be ineffective if MC concentration is extremely high.
	Bioslurry	- Provides optimized conditions for microbial growth and degradation of MC. - Provides both aerobic and anaerobic degradation conditions depending on contaminant and remedial goals. - Mostly effective on soil with high clay content.
	Soil washing	- Allows for reduction of total volume of contaminated soil and provides an alternative to remove reactive or ignitable compounds from soil particles. - Usually requires additional wastewater treatment.
	Low-temperature thermal desorption	- Used to treat low concentrations of MC. - During treatment contaminated soil is heated to separate contaminants by volatilization. - Thermal desorption is not very effective for treatment of explosives.
MC impacted soil and/ or GW	Chemical reduction or chemical oxidation	- Chemical remediation utilizes injection wells to deliver chemicals into contaminated soils. These chemicals, in turn, oxidize or reduce reactive compounds and transform them to non-toxic byproducts. - Some chemical reagents may be harmful and require handling by skilled professionals.
	Bioremediation	- Some MC may be degraded by naturally abundant microorganisms (e.g. perchlorate). - May not be effective if soil has a heavy clay content. - Mixed contaminant plumes may be more challenging to remediate

Electrochemical Treatment.

Electrolysis, the use of electrical energy to drive an otherwise unfavorable chemical reaction, is a technology that has been used to remediate industrial wastes and recently applied to explosives for wastewater treatment [53]. Some potential advantages of electrochemical treatment include the low cost of electricity compared with the cost of chemical treatments, relatively low capital costs, modular design, and the possibility of higher energy efficiency than thermal or photolysis treatments. Electrochemical treatment has been used at pilot scale to treat RDX, MNX and HMX as well as 2,4-DNT [54, 55].

In situ Chemical Oxidation

In situ chemical oxidation (ISCO) is a class of remediation technologies that consists of the in situ delivery of oxidants to treat contaminated GW. ISCO typically involves reduction/oxidation reactions that convert hazardous contaminants to nonhazardous or benign products that are less mobile or inert. Commonly used oxidants include potassium or sodium permanganate, Fenton's catalyzed hydrogen peroxide, hydrogen peroxide, ozone and sodium persulfate. More recently, ISCO has been used to conduct treatment of a wide-range of site contamination including MC and reactive residue. Examples of specific studies include use of a 1:1 mixture of O3 and H2O2 at a pH value of higher than 7 (peroxone) to generate hydroxyl radicals to promote degradation of RDX, HMX and several nitroaromatics in GW from the Cornhusker Army Ammunitions Plant. The study showed that target munitions were degraded by at least 64 %, with a destruction efficiency of 90% for RDX.

Ion Exchange Resins
An ion-exchange resin is used to physically separate the oxidizer component (nitrate anion) from the residual reactive commodity. This technology was used for treatment of perchlorate-contaminates water at a large scale production field site in California. Highly selective ion-exchange technology was used in this demonstration to remove perchlorate from contaminated GW after four regeneration cycles using a novel tetrachloroferrate (FeCl4-) displacement technique. This ion exchange-based technology enabled either quantitative destruction or recovery of eluted perchlorate for possible reuse, thus overcoming problems of conventional throwaway ion-exchange and/or brine regeneration methodologies [56].

Fenton Reactions
The Fenton chemistry and other metal-catalysed free radical chain reactions are initiated by the inadvertent by-products of aerobic respiration, such as hydrogen peroxide. Fenton reaction has been effective in treating volatile organic compounds (VOCs), light and dense non-aqueous phase liquids, petroleum hydrocarbons, PCBs, and nitroaromatic explosives [57]. A significant advantage of using the Fenton reaction for treatment of explosives is that destruction is rapid. Zoh and Stenstrom [57] investigated Fenton treatment of both RDX and HMX and reported 90% removal of RDX from a solution within 70 minutes, with HMX removal one-third as rapid. Most researchers have found that the Fenton reaction works best between pH 3 and 5, but destruction has been observed across a wider pH range (3 to 7).

6.4.2 Biological Treatment

Biological treatment relies on naturally abundant or bioaugmented microorganisms that degrade contaminants into less toxic byproducts. Bioremediation is most effective for diluted contaminant solutions of explosives and propellants.

DoD is currently developing or implementing six biological treatments for explosives-contaminated soils: aqueous-phase bioreactor treatment; composting, land farming, phytoremediation, and white rot fungus treatment, which are solid-phase treatments; and in situ biological treatment.

Aqueous Phase Bioreactor Treatment

As many types of bioreactor treatment technologies exist for MCs, two types of bioreactors are currently have been tested for the degradation of munitions: 1) the lagoon slurry reactor, which allows contaminants to remain in a lagoon, be mixed with nutrients and water, and degrade under anaerobic conditions, 2) the aboveground slurry reactor, which is either constructed onsite or purchased as a packaged plant [58].

Aqueous-phase bioreactors can be applied in treatment trains to achieve low contaminant concentrations and treat a variety of chemical compounds at the same time. However, the aqueous-phase bioreactors cause accumulation of degradation byproducts and, to date, have only been used to remediate explosives at a laboratory scale [58].

Composting

Compositing has been used at full scale to treat explosives waste since 1982. To date, composting has been shown to degrade TNT, RDX, HMX, DNT, tetryl, and NC in soils and sludges [59, 60]. Unlike incineration, composting causes production of an enriched product that can sustain vegetation. Moreover, compositing can be used for a variety of MCs, however, its use may be limited by the availability of amendment mixtures and presence of microorganisms that trigger degradation reactions of an MC.

Landfarming

In landfarming soils are excavated to treatment plots and tilled to mix in moisture, microorganisms and nutrients. Landfarming has been tested with a mixture of TNT, DNT and DNB in soils from explosive waste in California. The result achieved 30 to 40% degradation of the explosive compounds.

Phytoremediation

Phytoremediation, combined with the use of constructed wetlands is currently tested by the USACE for cleanup of contaminated soil with explosive residues of RDX, TNT, HMX and DNT. In phytoremediation, plant species, such as shrubs or trees, are used for uptake, degradation and accumulation of explosive compounds. To date, laboratory testing showed that plant nitroreductase enzymes degrade TNT, RDX and HMX. This process can be further utilized in the constructed wetlands for remediation of ground water contaminated with MCs.

White Rot Fungus Treatment

Lignin-degrading white rot basidiomycete, Phanerochaete chrysosporium, has been used for treatment of TNT- and HMX- contaminated soils. In bench-scale studies mixed fungal and bacterial systems, most of the reported degradation of TNT is attributable to native bacterial populations. High TNT concentrations in soil also can inhibit growth of white rot fungus. One study suggested that Phanerochaete chrysosporium was incapable of growing in soils contaminated with 20 parts per million (ppm) or more of TNT. In addition, some reports indicate that TNT losses reported in white rot fungus studies can be attributed to adsorption of TNT onto the fungus and soil amendments, such as corn cobs and straw.

In Situ Biological Treatment: In situ treatments can be less expensive than other technologies and produce low contaminant concentrations. The available data suggest, however, that in situ treatment of explosives might create more mobile intermediates during biodegradation. In addition, biodegradation of explosive contaminants typically involves metabolism with an added nutrient source, which is difficult to deliver in an in-situ environment. Mixing often affects the rate and performance of explosives degradation. Finally, effectiveness of in situ treatment is difficult to verify both during and after treatment. Physical/chemical approaches consist of changing the chemical or physical state of the contaminant.

6.4.3 Thermal Treatment

Thermal treatment strategies have been used for a variety of MCs. The descriptions below provide a general overview of types of thermal treatments available for GW or soil contaminated with explosive contaminants.

Hot Gas Decontamination

Hot gas decontamination is still in pilot-scale development but can be used for treatment of explosives-contaminated masonry or metallic structures. The method involves sealing and insulating the structures, heating with hot gas steam to 260°C (500°F) for a prescribed period of time, volatilizing the explosive contaminants, and destroying them in an afterburner. Operating conditions are site-specific. Contaminants are completely destroyed.

Incineration

Incineration processes can be used to treat the following waste streams: explosive-contaminated soil and debris, explosives with other organic or metals, initiating explosives, some bulk explosives, UXO, bulk explosive waste, and pyrophoric waste. In addition, incineration can be applied to sites with a mixture of media, such as sand, clay, water, and sludge, provided the media can be fed to the incinerator and heated for a sufficient period of time. With the approval of the DoD Explosives Safety Board, the Army considers incineration of materials containing less than 10% explosives by weight to be a nonexplosive operation. Soil with less than 10% explosives by weight has been shown to be nonreactive (that is, not to propagate a detonation throughout the mass of soil). (The military explosives to which this limit applies are secondary explosives such as TNT and RDX and their manufacturing byproducts).

6.4.4 Monitored Natural Attenuation (MNA)

MNA is a remedy that utilizes the capacity of the natural environment to mitigate contamination. There are several factors to consider when evaluating the site-specific lines of evidence (LOEs) related to the physical, chemical and biological attenuation pathways [61]. Pathways for MNA include degradation (biotic and abiotic), abiotic transformation, sorption and advection [62]. Under favorable conditions, the attenuation of MC will proceed without human intervention to reduce mass, toxicity, mobility, volume, or concentrations of contaminants in soil or GW [63]. The acceptance of MNA as a GW remedy has been firmly established for petroleum hydrocarbons

[64] and chlorinated solvent GW plumes [65] and also applied at nitroaromatic explosive sites [63] and perchlorate sites [66].

Following the initial release of MC into the environment, the fate of MC in GW is dependent on the contaminant, subsurface geochemistry and microbial community. For example, the lithology of the site affects contaminant fate in the subsurface due to the contaminant's affinity for sorption with organic matter. Additionally, biological degradation pathways impact the fate of MC with the redox environment of the soil or GW contributing to the rate of biotransformation. A key optimization concept is that of sequential implementation of multiple remedial.

6.4.5 Treatment Train Approaches

A key optimization concept is that of sequential implementation of multiple remedial alternatives, also known as a "treatment train." A single remedial technology is rarely the most cost-effective approach throughout the life cycle of a site clean-up project. The treatment train concept emphasizes that multiple remedial technologies often are needed to achieve cost-effective remediation at a given site.

7.0 FEASIBILITY STUDY

The primary focus of the FS is to ensure that appropriate remedial alternatives are developed and evaluated in such a manner that the information can be presented to a decision-maker and an appropriate remedy selected. The overall objectives of the FS are to:

- Develop and evaluate potential remedies that permanently and significantly reduce the threat to public health, welfare, and the environment;
- Select a cost-effective remedial action alternative that mitigates the threat(s); and
- Achieve consensus among DON, EPA, state, and local authorities regarding the selected response action.

The FS follows the stepped processes for development and screening of alternatives and detailed analysis of alternatives identified in Chapters 4 and 6 of EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* [67]. Through the FS, the Navy should achieve consensus among project stakeholders regarding the most appropriate remedial action. In the case of an NPL site, EPA concurrence should be obtained.

The process for developing and screening remedial action alternatives for MC is consistent with developing and screening remedial action alternatives for typical environmental contaminants, as supported by EPA *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* [67]. The remedial action alternatives for MEC that are developed and screened are different for terrestrial and underwater MRSs.

7.1 Feasibility Study Process

The FS process for underwater MRSs is the same for terrestrial sites, but with different response and process options.

7.1.1 Remedial Action Objectives

The general process for developing an FS includes assessing general remedial action process options and technologies, assembling these process options and technologies into remedial alternatives, and evaluating the alternatives for their suitability to address the threat/hazard at the MRS.

The remedial alternatives are developed on the basis of the specific circumstances at the MRS, and to accomplish the RAOs developed in the RI report. The RAOs, in turn, are based on:

- the specific nature and extent of MEC/MC identified at the site;
- the impacted media and depth/distribution of MEC/MC;
- the potential fate and transport of MEC/MC, and potential routes of exposure and receptors; and
- the identified cleanup goals.

RAOs provide a clear and concise description of what the remedial action should accomplish at a given site without specifying any given technology.

The following are examples of RAOs for a terrestrial and underwater MRS:

- Provide protection to human health and the environment by reducing and mitigating explosive hazard of MEC/MPPEH located on the surface and in subsurface soil such that hazards associated with the reasonably anticipated future land use can be mitigated
- Provide protection to human health and the environment by reducing and mitigating explosive hazards of MEC/MPPEH located on the bottom such that hazards associated with the reasonably anticipated future underwater use can be mitigated through use of underwater controls.
- For BRAC property, support transfer back to the community for the proposed land/underwater use.

RAOs for an MRS should be clear and concise, but afford sufficient flexibility to allow remedy optimizations and efficient project decision making.

Site-specific cleanup goals for MEC/MC are based on reasonably anticipated future land/water use (e.g., unrestricted, agricultural/aqua farming, commercial fishing/clamming, recreational), the type and characteristics of the contamination, the hazard/risk posed by the contamination, and other site-specific considerations (e.g., removal depth considerations based upon the ability to detect a TOI). Agreeing within the project team on the "current, determined, or reasonably anticipated future land/underwater use" for an MRS in turn drives the removal depth considerations.

7.1.2 Identification and Screening of Remedial Alternative Technologies and Process Options

The process of identifying, evaluating, and selecting the appropriate remedy for an MRS begins with a review of remedial technologies and methods that are appropriate to the site and the threat it poses. Figure 7-1 shows the general FS process for developing remedial alternatives for a MRS. A specific assessment of various remedial process options and technologies is conducted, and those options and technologies that would be potentially suitable for the site are retained, while those options and technologies that are not suitable are dropped from further consideration. The technologies and process options are assessed relative to the evaluation criteria of effectiveness, implementability, and cost.

7.1.2.1 Developing Remedial Alternatives

Remedial alternatives are assembled from the various process options and technologies that are retained from the initial evaluation of technologies. For the majority of MRSs, the following basic remedial alternatives are normally evaluated:

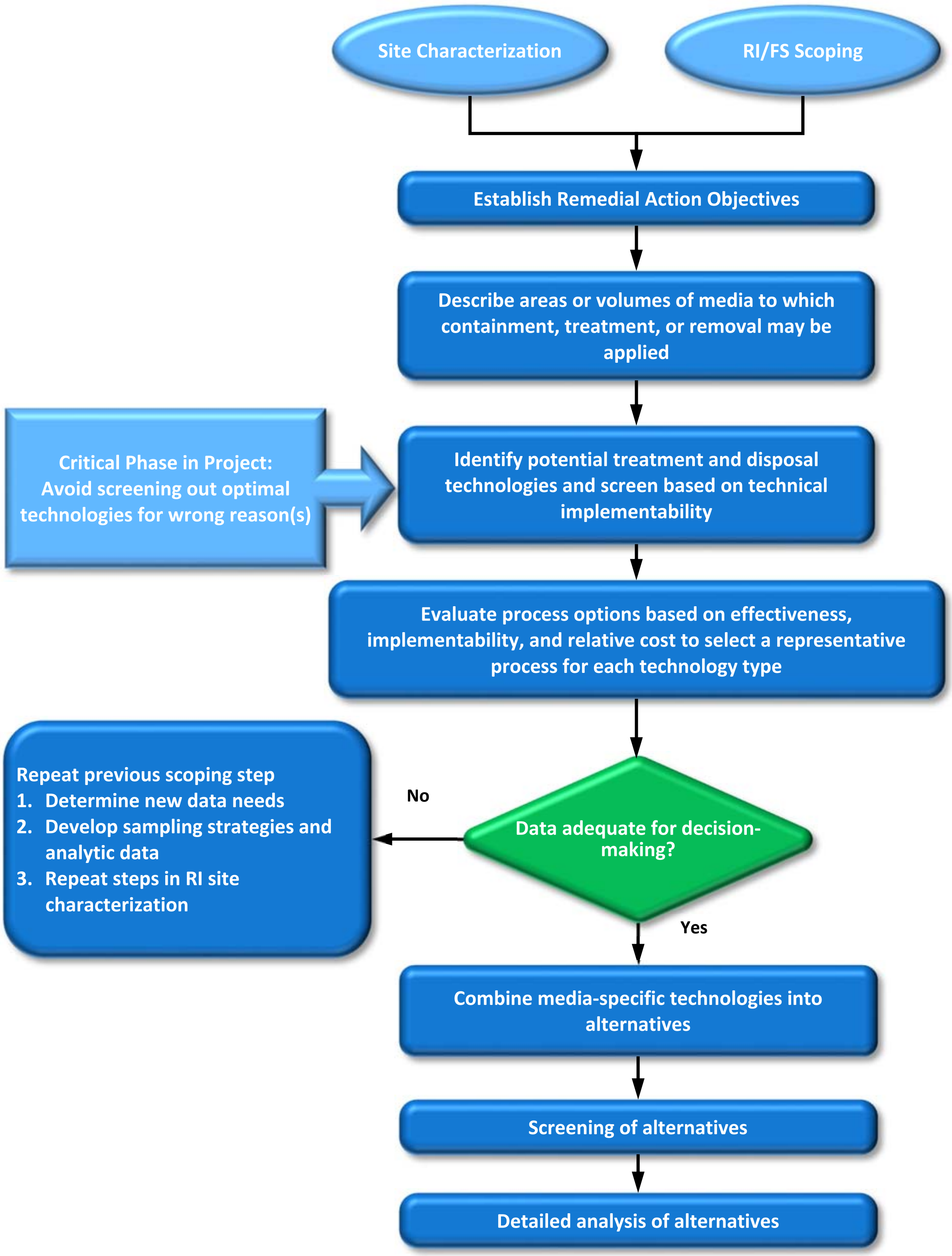

Figure 7-1. General Process for Developing Remedial Alternatives for a MRS

- No action;
- UU/UE;
- Removal; and
- Land/Underwater Use Controls.

Per DoD policy, the Navy and Marine Corps, while performing the FS, must consider a removal to remediate the site to a condition that allows unlimited use and unrestricted exposure (UU/UE), and removal to remediate the site to a protective condition that requires land use restrictions (i.e., LUCs or exposure controls). In addition, NAVFAC Optimization Policy for DON ER Program Sites, requires RAA and other requirements as part of the FS (see section 2.1.9). Figure 7-2 demonstrates the common remedial technologies applied at terrestrial MRSs, and several process options/technologies typically integrated into the alternatives (notably, advanced munitions classification would be a process option with the detection technology category). Figure 7-3 provides a list of remedial technologies and process options at an underwater MRS.

The design of remedial alternatives is based on land/underwater use and the potential depth of MEC. Interaction between potential receptors and MEC is also considered when designing a remedial action for an MRS. Other conditions that may be considered include the ability to collect, store, transport, and/or destroy the MEC at the site. For a MRS where MC or other incidental contamination is addressed; the number of potentially suitable remedial alternatives may be significantly larger. Remedial alternatives potentially applicable in which case are similar to those applicable at any common IR site.

The FS should describe technologies in general terms that permit a number of "technological approaches" to be applied within a "technology category" (e.g., use terms such as "AGC with capable technology" rather than "AGC with MetalMapper"). This provides more flexibility to the design engineer and minimizes unnecessary Explanations of Significant Differences and ROD Amendments when the remedy is applied in the remedial action phase. However, if the public's perception of the remedy is affected by the technology description, it may be appropriate to clarify which specific technology is being proposed.

No Action

The no action alternative is included in the FS, as required by the NCP, to provide a baseline to which other alternatives can be compared. The no action alternative is carried through the entire FS, but is not discussed to any great extent particularly if it is clear there is some risk/hazard.

Removal

Surface removal involves removing MEC that is observed/identified partially or wholly at the surface of an MRS. Surface removal may be guided by a visual or a geophysical survey. During a surface removal, qualified UXO personnel typically mark, identify, and record the locations of MEC for subsequent removal and destruction. MD or other metallic debris interfering with the surface removal, or surveying required to complete the surface removal, should also be collected for proper disposition.

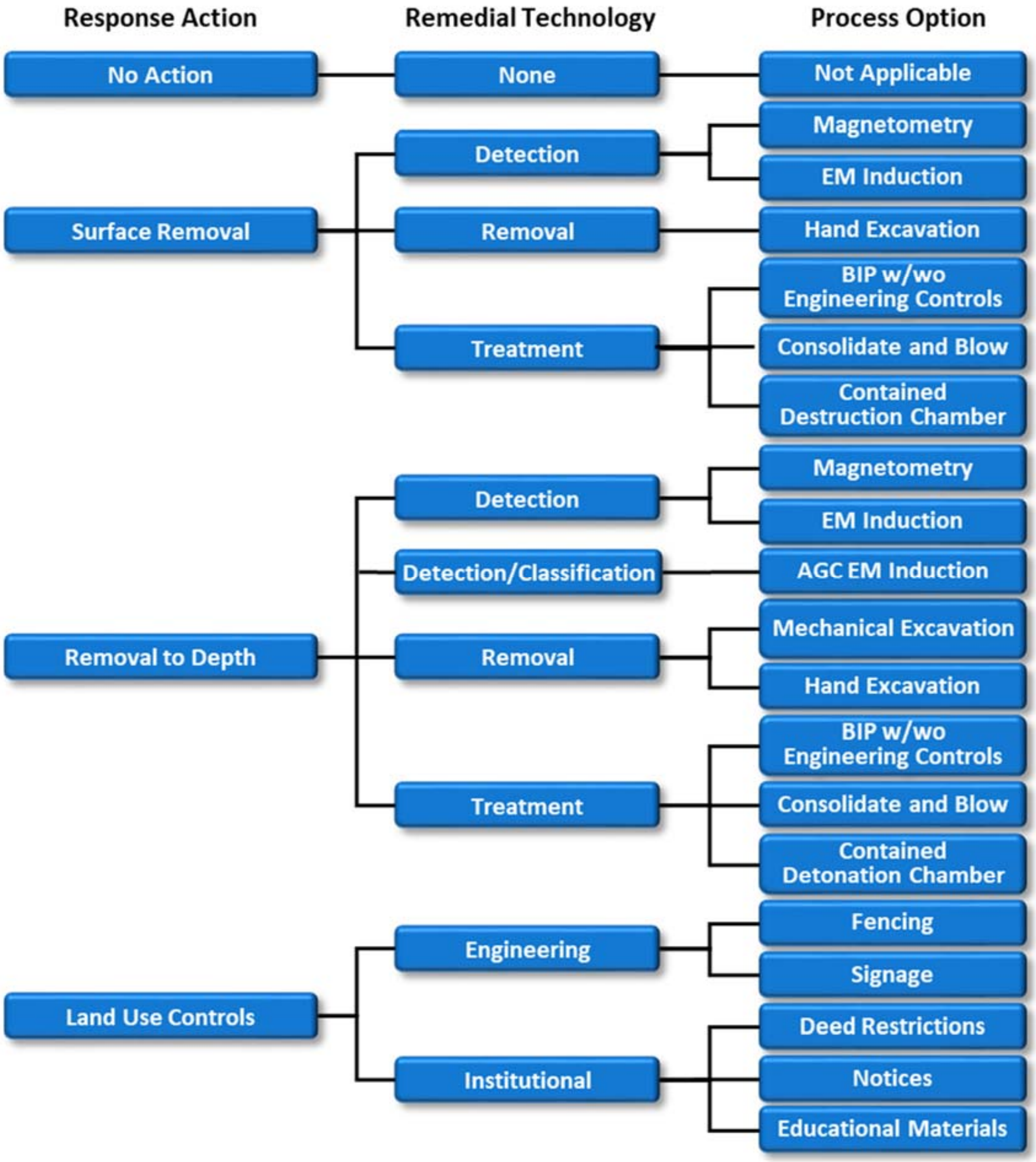

Figure 7-2. Common Remedial Technologies and Process Options for a Terrestrial Munitions Response Site

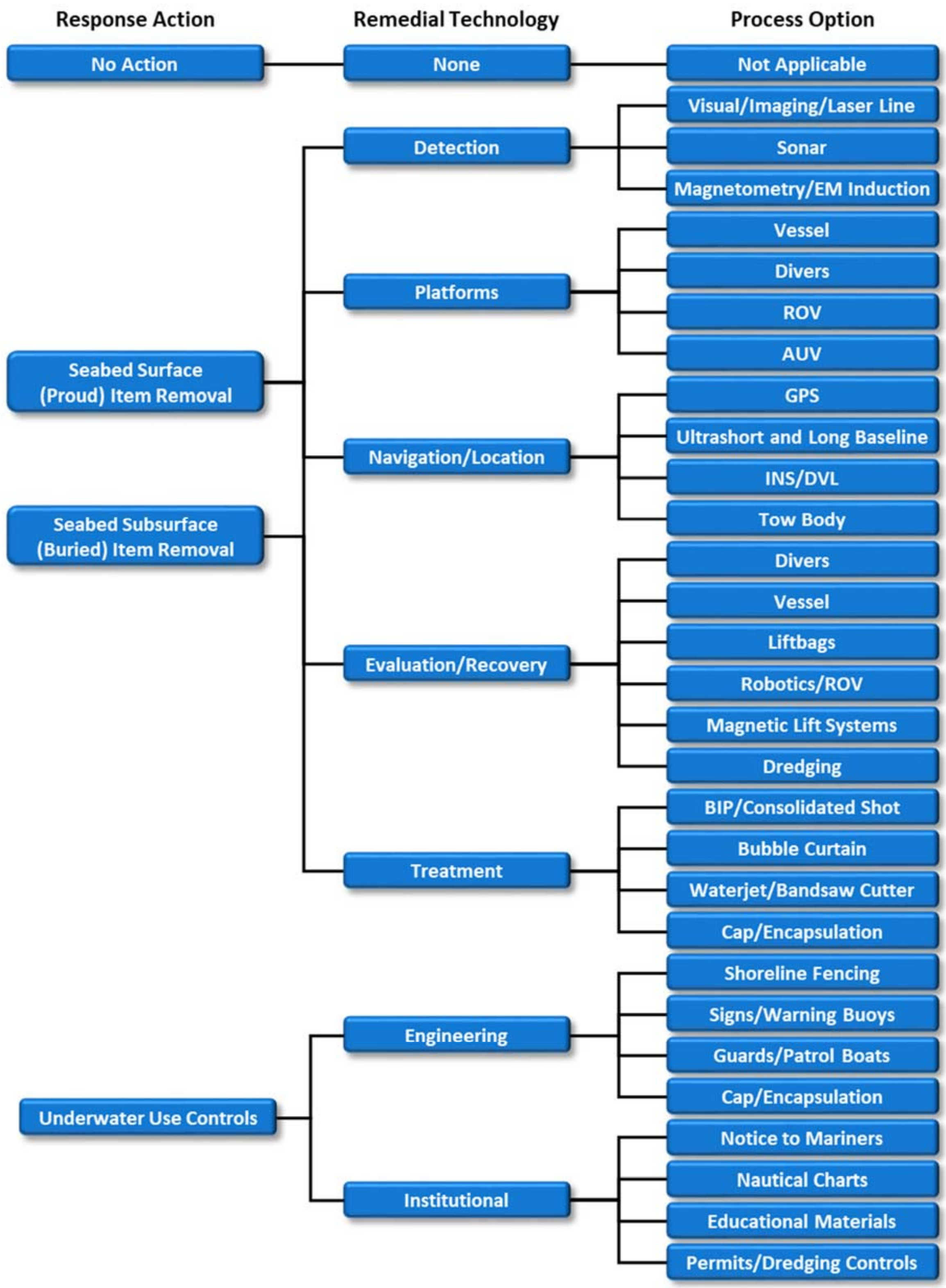

Figure 7-3. Common Remedial Technologies and Process Options at an Underwater Munitions Response Site

For MEC located in the subsurface, geophysical surveying is conducted to identify and locate anomalies for subsequent removal and destruction. Geophysical surveying is conducted in the same fashion as during the RI:

- Geophysical survey phase – the survey is implemented using the selected and demonstrated technology, and the resulting data are interpreted to identify MEC.
- Reacquisition phase – target anomalies are reacquired from geophysical survey data, documented, and removed.

During the RI, geophysical surveying is conducted to identify the presence or absence of MEC and, if present, assess the extent of MEC. Geophysical surveying conducted in support of a remedial action is intended to identify all MEC, and would typically cover the remaining site. The data gathered during a geophysical survey conducted to support a full site remedy are processed using appropriate techniques and a dig list is generated. Detection depth is a primary consideration during a subsurface removal.

MEC that is recovered during a removal-based remedial action is normally destroyed onsite for explosives safety reasons, either at the location of discovery or at a centralized location where all destruction takes place. In some cases, MEC may be transported offsite for destruction. Decisions associated with the destruction of recovered MEC are based on the nature of the MEC recovered, the risk associated with the disposal operation, and other site-specific considerations. All management, processing, and disposal of MEC must be done in compliance with DoD, DON, state, and federal requirements. Additional information on MEC disposal can be found in DON OP5 [1].

Removal-based remedial actions can be paired with LUCs to manage residual risk/hazard based on the overall level of confidence and certainty that all MEC will be addressed via removal.

Land/Underwater Use Controls
Land/underwater use controls include EC and institutional controls (ICs). ECs are remedies to contain and/or reduce contamination, and/or physical barriers intended to limit access to property. ICs include a variety of administrative and/or legal devices to maintain the viability and effectiveness of the selected remedy and any ECs. Chapter 6 discusses the options available for Land/underwater use controls.

7.1.2.2 Screening Remedial Alternatives

The next step in identifying, evaluating, and selecting an appropriate remedy for an MRS is to screen the remedial alternatives/methods using the three broad evaluation criteria of effectiveness, implementability, and cost:

- **Effectiveness**

This criterion focuses on the degree to which an alternative reduces toxicity, mobility, or volume through treatment; minimizes hazards/risks and affords long-term protection; complies with ARARs; minimizes short-term impacts; and how quickly the alternative achieves protection. Adverse environmental impacts that are predictable at this stage also should be considered in evaluating effectiveness. Calculations, assumptions, and references supporting these evaluations will be documented in the FS.

- **Implementability**

  This focuses on the technical feasibility and availability of the technologies each alternative would employ and the administrative feasibility of implementing the alternative. Alternatives that are technically or administratively infeasible or that would require equipment, specialists, or facilities that are not available within a reasonable period may be eliminated from further consideration. Factors such as constructability, expected opposition from the public, impact on the installation's mission, compatibility with planned land uses, and availability of material, equipment, technical expertise, or off-site treatment and disposal facilities also may be considered in evaluating implementability.

- **Cost**

  When comparing alternatives, the life-cycle cost of each alternative shall consider the capital cost plus all future costs. Future costs include future single payment costs and recurring costs, such as long-term costs for operation, maintenance and monitoring.

During the screening of remedial alternatives based on effectiveness, implementability, and cost, the evaluation is typically conducted on a qualitative or semi-quantitative basis. Based on the evaluation, a reasonable number of alternatives is selected for detailed analysis. The results of the initial screening of alternatives should form the basis of the Navy's request to state agencies to provide state ARARs.

The initial screening of remedial alternatives should include completion of the RAA, as discussed in Section 2.1.6. As described in the DON ER Program optimization policy [10], the point of the FS process when remedial alternatives have been identified and screened but prior to detailed evaluation is the appropriate time to conduct a third-party RAA review. Details regarding the process required to complete the RAA and the RAA template are provided in the final RAA guidance, which was issued in April 2012 [11]. Following the initial screening of remedial alternatives, those alternatives that are most suitable to accomplish the RAOs, taking into considering site-specific factors including future land use, are retained for detailed evaluation.

7.1.2.3 Detailed Analysis of Alternatives

Once a list of viable alternatives has been retained from the initial screening phase, the alternatives are evaluated against EPA's nine FS evaluation criteria. The purpose of this step is to further evaluate and compare the alternatives. EPA's nine FS evaluation criteria are defined in the NCP (Section 300.430(e)(9)(iii)). During the detailed evaluation, the alternatives are assessed with respect to each of the nine evaluation criteria, and then the alternatives are also evaluated comparatively against each other using the nine evaluation criteria as context. State and local community acceptance may not be evaluated fully until the Proposed Plan is published and public review is completed during Remedy Selection. Table 7-1 shows the nine EPA FS evaluation criteria.

Table 7-1. Summary of the Nine NCP Criteria

Category	Criteria	Description
Threshold Criteria	Overall protection of human health and the environment	Addresses whether or not a specific alternative will achieve adequate protection and describes how the contamination at the site will be eliminated, reduced, or controlled through treatment, engineering, and/or LUCs.
	Compliance with ARARs	Addresses whether or not a remedial alternative meets all related federal and state environmental statutes and regulations. An alternative shall comply with ARARs, or be covered by a waiver, to be acceptable.
Primary Balancing Criteria	Long-term effectiveness and permanence	Addresses the ability of a remedial alternative to maintain reliable protection of human health and the environment over time. It also considers the risk posed by treatment residuals and untreated materials.
	Reduction in toxicity, mobility, or volume through treatment	Addresses the preference for RAs that use treatment technologies that permanently and significantly reduce toxicity, mobility, and/or volume of contaminants.
	Short-term effectiveness	Addresses the period of time needed to implement the remedy and any adverse impacts that may be posed to workers, the community, and the environment during construction and operation of the remedy.
	Implementability	Addresses the technical and administrative feasibility of implementing a remedial alternative from design through construction and operation. Factors such as availability of services, materials, and operational reliability are considered.
	Cost	Addresses the total cost of a remedial alternative, including consideration of the capital costs, annual O&M costs, and net present value (NPV) of these costs.
Modifying Criteria	State acceptance	Addresses the acceptability of a remedial alternative to state regulatory agencies.
	Community acceptance	Addresses the acceptability of a remedial alternative to the public.

Shaded rows represent criteria that provide opportunities for GSR assessment.

The DON ER Program optimization policy [16] also requires that a GSR evaluation be completed for each of the alternatives retained for detailed analysis in the FS. As part of this step, remedy footprint analysis using the SiteWise™ tool shall be conducted in accordance with *DON Guidance on Green and Sustainable Remediation* [17]. Other tools, such as the AFCEE SRT™ or similar GSR tools can also be used, but they can only be used in conjunction with or after an analysis using the SiteWise™ tool has first been performed. The GSR metrics evaluated during this analysis can be incorporated into the review of the CERCLA criteria during the FS. More discussion of the GSR procedures and integration of the analysis into remedy selection documents is provided in the DON GSR guidance.

7.1.4.1 Threshold Criteria

Threshold criteria must be met for an alternative to be selected as the remedy to be implemented, or these requirements must be specifically waived. For an MRS, the primary objective is to reduce an imminent hazard/risk while meeting ARARs.

Overall Protection of Human Health and the Environment

The overall protection of human health and the environment is a measure of the alternative's ability to prevent adverse impact on human health and the environment, essentially related to the magnitude of residual risk/hazard following the remedy.

For MEC, assessment of this criterion must evaluate whether or not removal to certain depths will reduce risks/explosive hazards to acceptable levels based on future land/underwater use scenarios. For MC, assessment of this criterion must take into consideration what actions are necessary to lower chemical risk to acceptable levels, with the focus being on both human and ecological health. There are currently no approved methodologies for conducting HAs for MEC at underwater sites. Limited ecological toxicity and fate data does support that underwater MC does not pose an ecological risk. Site-specific information, including the MEC/COCs, receptors, and exposure routes, should be used to evaluate these risks/hazards in order to meet the objectives identified for a specific project.

Compliance with ARARs

ARARs are federal and state laws and regulations that are evaluated when evaluating and selecting remedial actions. Applicable requirements are those cleanup standards, standards of control and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site. Relevant and appropriate requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations issued under federal or state environmental law that, although not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site so that their use is well-suited to the particular site.

ARARs may be categorized as chemical-, location-, or action-specific:

- **Chemical-specific ARARs** set health or risk-based concentration limits or ranges in various environmental media for specific hazardous substances, pollutants, or contaminants.

- **Location-specific ARARs** set restrictions on activities within geographic areas or specific settings, such as wetlands, floodplains, and shorelines, and depend on the characteristics of the MRS and its immediate environment.
- **Action-specific ARARs** set controls or restrictions on particular kinds of remedial activities that may be selected to accomplish a remedy, and may specify performance levels, actions, or technologies to be used to manage hazardous substances, pollutants, or contaminants.

Some ARARs may be the CWA, Clean Air Act, RCRA, Endangered Species Act, National Historic Preservation Act Sec 106, Native American Graves Protection and Repatriation Act, and Coastal Zone Management Act. Numeric standards such as National Ambient Water Quality Criteria (NAWQC) and maximum contaminant levels may apply. In certain instances, there may not be an ARAR that addresses a particular remedial action, or a particular physical setting, or a particular contaminant. For MEC, some specific examples of ARARs include impacts to natural/cultural resources through MEC removal alternatives, and transportation, disposal, and endangered species regulations. Consultation with NMFS may be required when the ESA, MMPA and/or essential fish habitats (EFHs) provisions are identified as ARARs. The RPM should consult local counsel or regulatory specialists to determine which ARARs apply. In addition, EO 13089 requires Federal activities to develop methods to mitigate potential damage when actions could impact coral reefs. Mitigation to eliminate or minimize the impact to the sensitive receptors and habitats is required, but the selected mitigation method can be varied. Potential options for mitigating impacts associated with these ARARs include:

- Avoidance of species and habitats,
- Work during seasonal migration periods, and
- Operational avoidance.

Additional ARARs that may need to be considered depending upon the remedial action being evaluated include:

- Coastal Zone Management Act consultation – impact on recreational activities such as fishing, surfing, swimming, scuba diving, boating, etc;
- National Historic Preservation Act Section 106 – impact on historical wrecks and structures;
- Rivers and Harbors Act section 10 permit – work or structures in, over, or under navigable waters of the United States;
- Fish and Wildlife Coordination Act consultation; and
- Clean Water Act Section 404 permit – discharge of dredged or fill material into U.S. waters.

For MC, some specific examples of ARARs include promulgated cleanup levels (e.g., for soil or GW), waste disposal regulations, and treatment alternative regulations.

Also, prior to survey operations at some underwater MRSs, notification must be made to the U.S. Coast Guard, which will publish a notice to mariners.

Remedial actions that are conducted entirely onsite need only comply with the substantive aspects, and not the administrative or procedural aspects of ARARs such as obtaining permits or administrative reviews. Remedial actions that are not conducted entirely onsite need to comply with substantive and administrative aspects, including obtaining permits. An example of a remedial action that is not conducted entirely onsite is where the action requires the off-site disposal of MEC. In that case, all manifesting and permitting requirements, including administrative requirements, related to the transportation and disposal of MEC as hazardous waste must be met.

In addition to ARARs, the project team should evaluate to be considered (TBC) requirements. TBCs can be additional advisories, criteria, or guidance developed by EPA, or other state and federal agencies. Since TBCs are not ARARs, they are not binding but rather are additional factors to consider in developing CERCLA remedies. TBC requirements should be applied with caution because, although they have no legal status prior to ROD execution, once a TBC is included in a ROD as a remedial objective, it becomes legally binding.

7.1.4.2 Balancing Criteria

Balancing criteria form the basis for comparing and differentiating among remedial alternatives that successfully meet the threshold criteria. There are five balancing criteria, and all are weighted equally to every extent possible in comparing remedial alternatives.

Long-Term Effectiveness and Permanence
This balancing criterion addresses the ability of a remedial alternative to maintain reliable protection of human health and the environment over time. It also considers the risk posed by residual contamination and untreated materials. This criterion addresses the adequacy and reliability of controls such as containment systems (e.g., caps and the associated maintenance concerns to address erosion, frost heave of MEC/MPPEH, etc.) and LUCs that are necessary to manage residual contamination and untreated waste.

For MEC, this criterion is typically evaluated by determining if there is an acceptable explosive hazard reduction. For MC, this criterion is typically evaluated by determining if there is an acceptable chemical risk reduction. For both MEC and MC, this criterion is assessed in terms of the reliability of any required LUCs.

Specific considerations for MEC at underwater MRSs include ensuring the proper technology is selected to perform the clearance (if necessary) to meet QA/QC criteria based on site-specific conditions related to the underwater environment, identifying and achieving an acceptable explosive hazard reduction through implementation of the remedial alternative, and ensuring reliability of underwater use controls. For MC, reliable technologies should be selected for detection and treatment, and an acceptable reduction in chemical risk should be achieved through implementation of the remedial alternative.

Reduction of Toxicity, Mobility, or Volume through Treatment
This criterion assesses the relative amount of hazardous substances, pollutants, or contaminants that will be destroyed, treated, or recycled, as well as the degree to which the treatment process would be irreversible. This criterion is also assessed with consideration to the type, quantity, or volume of residuals that will remain, and further considering the persistence, toxicity, and mobility of these residuals.

For MC, toxicity, mobility, and volume are all factors that can be evaluated. For terrestrial MEC, toxicity and mobility aren't usually relevant as the concern is typically an imminent explosive hazard. The reduction of volume is the primary consideration for MEC. For both MC and MEC, this criterion is considered based on the degree to which the threat is reduced. For MEC/MC, potential response actions and considerations when evaluating this criterion include, for example:

- Removal/Dredging results in volume reduction and the treatment is irreversible.
- Capping results in mobility reduction.
- Natural Attenuation results in volume and toxicity reduction.

When evaluating this criterion, the project team should consider the MEC present at the MRS and the process of disposing the MEC.

Short-Term Effectiveness
This criterion considers short-term risks to the community and the potential impact to site workers during remediation, as well as the potential for ecological impacts due to remediation and the time required to complete remediation.

Worker and community safety is primarily addressed through the use of EZs and ECs during the remedy and ICs established after the remedy. EZs limit the exposure to the public and non-essential workers by cordoning off the maximum fragmentation distance (MFD) of the MGFD during intentional detonations, and to the hazardous fragmentation distance (HFD) of the MGFD for unintentional detonations. ECs, such as those provided by DDESB Technical Paper 16 (TP16), Buried Explosion Module, can reduce the MFD considerably (sometimes to 0 ft) during intentional detonations, thereby allowing work to proceed without closing public highways or interfering with other normal daily activities outside the installation boundaries [68]. Essential workers, normally the UXO personnel, are protected from blast and fragmentation through the use of ECs (e.g., shielding, barricades, etc.) and distances designed to reduce the effects of blast pressure to acceptable levels.

Additional site concerns for worker safety include physical hazards associated with working on site, such as steep terrain, poison vegetation, insects, snakes, etc. There are also hazards associated with locating and identifying the munitions including identification of the munition when it is located in wetlands (e.g., excavations that flood during investigation), work on steep slopes and/or hazardous terrain or in inclement weather. Dig and haul typically involves a large amount of truck traffic that can impact a local community in the short term. Dredging can also have a short term impact on the community due to the noise produced and the handling of the dredge spoils. There can also be socioeconomic impacts to specific communities depending on site location and the location of site access routes. Some public traffic routes/waterways may need to be closed as part of the EZ during implementation of the remedial action. Worker safety at underwater MRSs can include considerations for entanglement, weather conditions, and visibility.

Ecological impacts vary with the specific site. For instance, alternatives requiring a significant amount of vegetation removal can have a larger impact on the environment. Another consideration can be the impact to an endangered species that may have a specific nesting season or location.

GSR is normally evaluated with the short-term effectiveness criteria. During a MR project, evaluation of various alternatives should be viewed in light of their GSR potential. Some of the GSR options that may be applicable to an MRS include:

- Vegetation removal – mechanical vs. manual
- Anomaly detection – vehicle towed vs. man portable
- Anomaly dig/don't dig decision – dig all anomalies vs. dig only anomalies selected by classifier
- Small arms ammo projectiles – dig and haul vs. dig and sift
- Subsurface anomaly removal – mass excavation and removal vs. selected anomaly removal

Implementability

This criterion is associated with the technical ability to construct and operate the alternative, including the availability of equipment, services, materials, and infrastructure, the reliability of the technologies used, ease of undertaking the remedy and any additional remedial action (if necessary), and the ability to monitor the effectiveness of the remedy. This criterion is also associated with the administrative feasibility of the alternative, including the activities that need to be coordinated with other offices and agencies.

Alternatives that are technically or administratively infeasible or that would require equipment, specialists, or facilities that are not available within a reasonable period may be eliminated from further consideration. Factors such as constructability, expected opposition from the public (e.g., closing of public traffic routes/waterways), impact on the installation's mission, compatibility with planned land uses, and availability of material, equipment, technical expertise, or off-site treatment and disposal facilities also may be considered in evaluating implementability.

Site-specific conditions at underwater sites can increase the difficulty of implementing certain remedial actions, such as placement of a cap at a site with high wind energy or tidal currents, or dredging a site with steep underwater topography. These conditions can be overcome, but additional measures may be required to effectively implement the alternative under these conditions. At remote sites, the availability of equipment and infrastructure needed to implement an alternative may limit implementability, and should be evaluated as part of this criterion. The proper equipment must be used so that QA/QC requirements can be met.

Administrative feasibility also plays a large role at underwater MRSs. Activities need to be coordinated with other offices and agencies, and at underwater sites several additional agencies may be involved including NOAA, NMFS, and other natural resources stakeholders. This may particularly be the case if ESA, MMPA, or EFH are identified as ARARs and work around endangered or protected species and habitats is required. If long-term monitoring is required as part of the remedy, access agreements for implementation of the monitoring activities should also be considered.

Cost

This balancing criterion is based on the direct and indirect capital, remedial action operation, and long-term monitoring costs associated with a remedial alternative, and may also include an evaluation of the value of land. When comparing alternatives, the life-cycle cost of each alternative shall consider the capital cost plus all future costs. Future costs include future single payment costs and recurring costs, such as long-term costs for operation, maintenance and monitoring.

The life-cycle cost is generally computed as a net present value cost with discounts applied over a 30-year time period. The 30-year duration is consistent with the NCP, but does not represent an actual limitation on the duration of the remedy. Consistent with the EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* [67], cost estimates should be accurate to -30% to +50% to provide appropriate basis for comparison between alternatives.

Numerous resources are available to facilitate FS cost estimating, and informed estimates and assumptions can be used where specific cost backup cannot be obtained. Appropriate contingencies should be built into FS costs to account for uncertainties.

7.1.4.3 Modifying Criteria

Modifying criteria are generally considered at the time of remedy selection and documented as part of the Proposed Plan/ROD.

State Acceptance

Communication with the regulatory stakeholders is critical throughout the RI/FS for an MRS. State acceptance evaluates the technical and administrative issues and concerns the state may have regarding each of the alternatives. This criterion will be addressed in the ROD once comments on the RI/FS report and proposed plan have been received.

Community Acceptance

Community acceptance can be estimated based on public outreach, including RAB meetings and public meetings. Ultimately, this criterion is the last phase of remedy selection and cannot be sufficiently evaluated during the RI/FS. The public must have opportunity to review and comment on the Proposed Plan for an MRS. Alternatives which are strongly supported or opposed by community stakeholders must be considered.

Final community acceptance is assessed after the public comment period for the Proposed Plan. Community concerns are then addressed through selection of the remedy, documentation of this selection in the ROD, and the inclusion of a responsiveness summary in the ROD.

7.1.5 FS Reporting

The FS should summarize the results of the RI, and detail the development of RAOs, remediation goals, and investigation areas. The FS should summarize the development of project ARARs, the identification and screening of technologies and process options, the development and screening of remedial alternatives, and the detailed and comparative assessment of alternatives. Tabulated summaries of various screening and evaluation stages aid in the communication of the FS results.

8.0 RI/FS REPORT

The FS report can be combined with the RI report to form a RI/FS report, but the RI and FS reports can also be prepared separately. The RI/FS report is a significant document, as it forms the basis for the selection of the remedy and the DDs. The selected remedy is then documented in a Proposed Plan and ROD.

The RI portion of the RI/FS report should document the investigation activities completed at the MRS. Information that should be presented includes the MRS background, a description of the physical characteristics of the site, a discussion of the objectives for the investigation activities, a description of the data collection methods and analysis results, the updated CSM, the baseline risk/HA, and the recommended RAOs.

The recommended RI report format is as follows:

Executive Summary
- Introduction
- Study Area Investigation
- Physical Characteristics of the Study Area
- Nature and Extent of Contamination
- Fate and Transport
- Risk/HA
- Summary and Conclusions

Appendices

The FS portion of the RI/FS report should summarize the results of the RI, detail the development of ARARs and resulting preliminary remediation goals, identify and screen the general response alternatives, identify and screen preliminary alternatives, provide a detailed alternative description and evaluation using the nine CERCLA criteria for those alternatives selected from the preliminary screening process, and provide a comparative analysis for the detailed alternatives using the nine CERCLA criteria.

The recommended FS report format is as follows:

Executive Summary
- Introduction
- Identification and Screening of Technologies
- Development and Screening of Alternatives
- Detailed Analysis of Alternatives

Appendices

An example RI/FS report table of contents is provided in Table 8-1. Additional details regarding the CERCLA RI/FS process and reporting can be found in the EPA *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* [21].

Table 8-1. Example Table of Contents for RI/FS Report

Executive Summary
Abbreviations and Acronyms
1.0 Introduction
  1.1 Project Background
  1.2 Project Objectives and Scope
  1.3 MEC/MC of interest
2.0 MRS Setting and Previous Investigation
  2.1 Site Description and History
  2.2 Physical Characteristics of the MRS
  2.3 Cultural and Natural Resources
  2.4 Land Use
  2.5 Summary of Previous Investigations
    2.5.1 Preliminary Assessment
    2.5.2 Engineering Evaluation/Cost Analysis
    2.5.3 Site Inspection, etc.
3.0 RI Field Work
  3.1 MEC Activities (Summary of DFW)
    3.1.1 Vegetation Removal
    3.1.2 Surface Removal, Geophysical Survey, etc.
    3.1.3 Quality Control and Assurance
  3.2 MC Activities (Summary of Sampling Approaches)
    3.2.1 Surface Soil Sampling Using Increment Sampling Approach
    3.2.3 Subsurface Soil Discrete Sampling, etc.
    3.2.4 Quality Assurance/Quality Control
4.0 Nature and Extent of Contamination
  4.1 Nature and Extent of MEC
  4.2 Nature and Extent of MC
  4.3 Updated CSM
    4.3.1 Current and Potential Future Land Uses
    4.3.2 Potential Sources of MEC/MC
    4.3.3 Potential Exposure Pathways
    4.3.4 Potential Human and Ecological Receptors
5.0 Contaminant Fate and Transport
  5.1 Possible Routes of Migration
  5.2 Contaminant Persistence
  5.3 Contaminant Migration
6.0 MEC Hazard Assessment
  6.1 MEC HA Methodology
  6.2 MEC HA Results
7.0 Risk Assessment
  7.1 Human Health Risk Assessment

7.1.1 Data Analysis
7.1.2 Exposure Assessment
7.1.3 Toxicity Assessment
7.1.4 Risk Characterization
7.2 Ecological Risk Assessment
7.2.1 Data Analysis
7.2.2 Exposure Assessment
7.2.3 Toxicity Assessment
7.1.4 Risk Characterization
8.0 Summary of Findings and Recommendations
8.1 Summary of Findings
8.1.1 Nature and Extent of Contamination
8.1.2 Fate and Transport
8.1.3 Hazard/Risk Assessments
8.2 Conclusions
8.2 Data Limitations and Recommendations for Future Work
8.2 Recommended RAOs
9.0 Feasibility Study
9.1 Introduction
9.2 Identification and Screening of Response Actions
9.2.1 Remedial Action Objectives for MEC and MC
9.2.2.1 Summary of ARARs for MEC and MC
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