Underwater Munitions Response Site (MRS) Management Technologies

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NAVFAC ESC

RITS Spring 2011

Presentation Overview

- ▶ Policy
- Underwater MRS Characteristics and Challenges
- Technologies to Investigate and Remediate a MRS
- Munitions Constituent (MC) Toxicity and Munitions of Explosive Concern (MEC) Mobility Model
- Case Studies
- Summary

Navy Underwater MRS Policy

- **Shallow water areas where munitions releases are known or suspected to have occurred and where:**
  - **Navy actions are responsible for the release**
  - **Munitions are covered by water no deeper than 120 feet**
    - Munitions located in waters between high and low tides will be considered terrestrial

Scuba Diving Experience and Training Class
Photo Courtesy of U.S. Navy

3 **Policy** RITS Spring 2011: Underwater MRS

Per Navy MRS policy, an underwater munitions response site:

- is covered by water at low tide,
- has no more than 120 ft water covering the site.

If the site is deeper than 120 ft, it is **not** considered an underwater munitions response site. If the site is “dry” at low tide, then the site is a **terrestrial** site.

Navy Underwater MRS Policy (cont.)

The site is not:

- Part of, or associated with, a designated operational range (terrestrial or water)
- A designated water disposal site
- A Formerly Used Defense Site (FUDS)
- A result of combat operations
- A maritime wreck
- An artificial reef

USS Killen before Becoming a Target Ship
Photo Courtesy of National Archives

USS Shaw Exploding during the Japanese Raid on Pearl Harbor
Photo Courtesy of U.S. Navy

4 Policy RITS Spring 2011: Underwater MRS

A site can not be designated a munitions response site if the site can be categorized as one of the bulleted items. Other than these bulleted items, if a site has munitions in it, then the site is a munitions response site.

Navy Underwater MRS Policy (cont.)

- Underwater ER,N MRSs included in MRP schedule goals
  - 2007 Preliminary Assessment completion date
  - 2010 Site Inspection completion date
  - 2020 Remedy In Place/Response Complete date
- Funded by ER,N (MRP) or BRAC under CERCLA and RCRA
  - Phase 4 costs estimated at greater than $1.1B for 33 sites/AOCs
- Site cleanup is a hazard/risk-based determination
  - For MCs (contaminants) follow existing risk assessment guidance
  - Explosive hazard must be assessed on a site-specific basis (no standard model for assessing explosive hazard)
  - No standardized underwater UXO approach

Seahawk Firing an AGM-119B Penguin Anti-ship Missile
Photo Courtesy of U.S. Navy

5 Policy RITS Spring 2011: Underwater MRS

- Underwater ER,N MRS sites follow the same schedule as terrestrial base munitions sites. However, the technologies, procedures, and policies are not as well developed as terrestrial MRS sites because funding went to the terrestrial sites first.
- Environmental restoration costs are high - typically billions of dollars – for underwater MRS sites. As technologies develop, prices will hopefully decrease.
- Typically, underwater MRS site clean ups are risk based which requires a risk assessment. However, currently there is no standard for conducting underwater MRS risk assessments.

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Underwater MRS Characteristics

- **Before you investigate, know your site's environment**
  - **Ocean, bay, river, lake, island**
  - **Depth, currents, wave action, tides, water clarity, turbulence**
  - **Local weather**
  - **Bottoms (soft, hard, sediments)**
  - **Habitat (sea grass beds, coral reefs, open bottom, swamps, marshes)**
  - **Inhabiting biota (especially T&E species)**

Vieques Island Live Impact Area
Photo Courtesy of U.S. Navy

UXO Laying Proud on Rock Bottom
Photo Courtesy of ESTCP

7 Underwater MRS Characteristics & Challenges RITS Spring 2011: Underwater MRS

Know what your environment is. This is very important.

- Understanding the environment of a site is much easier for terrestrial sites because you can physically see the environment (e.g., where trees, water, etc.). Underwater environments are totally different. If you aren't a diver, then it's hard to understand the environment, how it changes, and how different things are underwater.
- Underwater forces play an important role at a site because of the dynamic nature of water. Fluid forces change with seasons (especially during storms) and these forces cannot be seen.
- Talk with people familiar with the environment: professional, commercial, and recreational divers. For example, people who dredge should be consulted to help understand the environment.

Underwater MRS Challenges

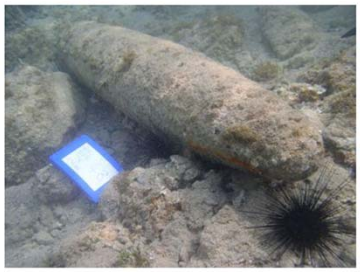
- **MEC detection/ID challenge magnified by:**
  - **Environmental and operational conditions**
    - Choosing the right technology and equipment for the site
    - Topography – bottom obstructions and navigation hazards
    - Geology impacts detection technology selection
    - Poor control of sensor to bottom standoff distance
    - Detection sensor capability
    - Detection of small items not possible with survey technologies
    - Sensor interference from metallic bottom clutter
    - Most anomalies detected are non munitions metal debris
    - High cost to investigate and identify non-hazardous items

8 Underwater MRS Characteristics & Challenges RITS Spring 2011: Underwater MRS

- One of the biggest challenges is choosing the **right** equipment for **your** site. There are lots of equipment choices. However, certain equipment only works on certain sites, and there are limitations to technologies.
- For example, varying topography can impact detection limits as it did at Pearl Harbor where there is significant of debris on the bottom.
- Detection of small items can be a problem. Currently, no technology is available to find items the size of 50 caliber shells.

Underwater MRS Challenges (cont.)

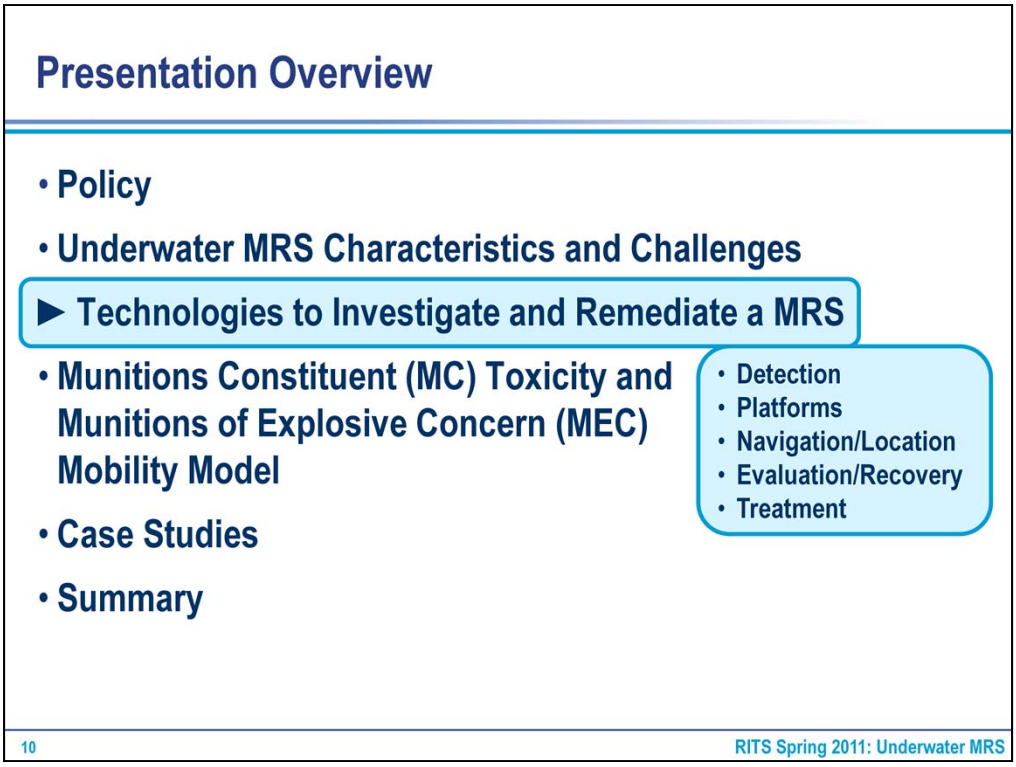
- **MEC detection/ID challenge magnified by:**
  - **Dive operations slower than terrestrial operations**
    - Navy dive safety compliance guide USACE EM 385-1-1 (Safety Manual)
  - **Poor visibility in water**
  - **Dynamics of the near shore environment and meteorological conditions**
    - Wind, waves, & currents
  - **Determining status of fuzing**
    - DMM – unfuzed, unarmed
    - UXO – fuzed, armed
- **MEC treatment environmental impact challenge**



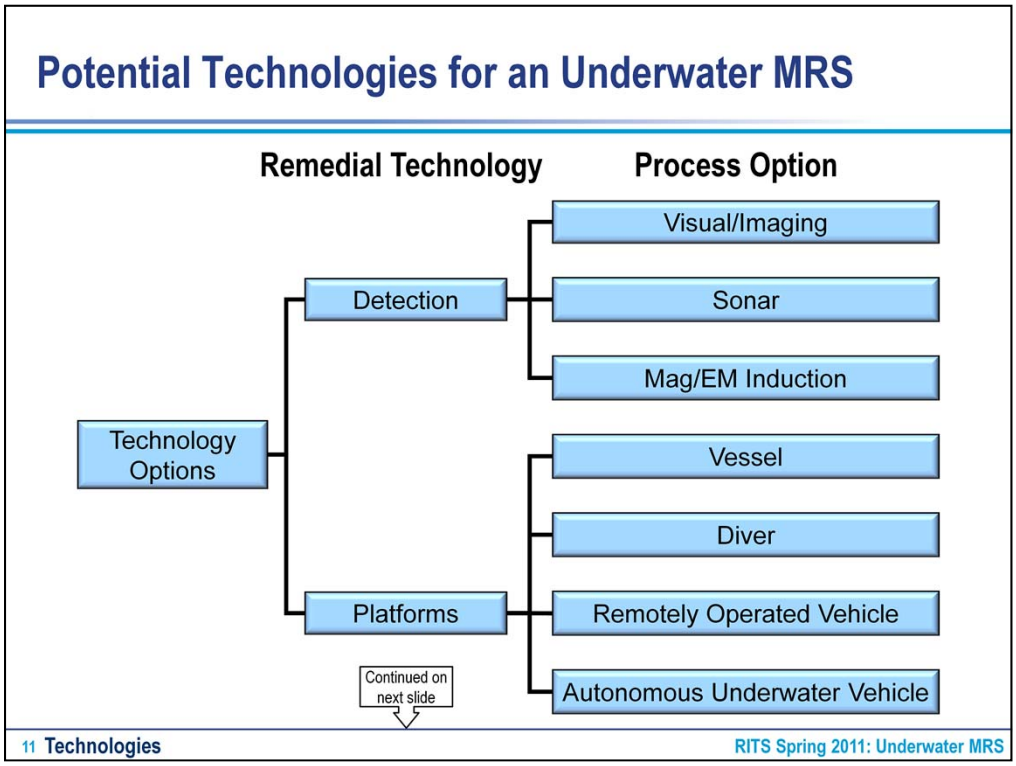
Photos Courtesy of U.S. Navy

9 Underwater MRS Characteristics & Challenges RITS Spring 2011: Underwater MRS

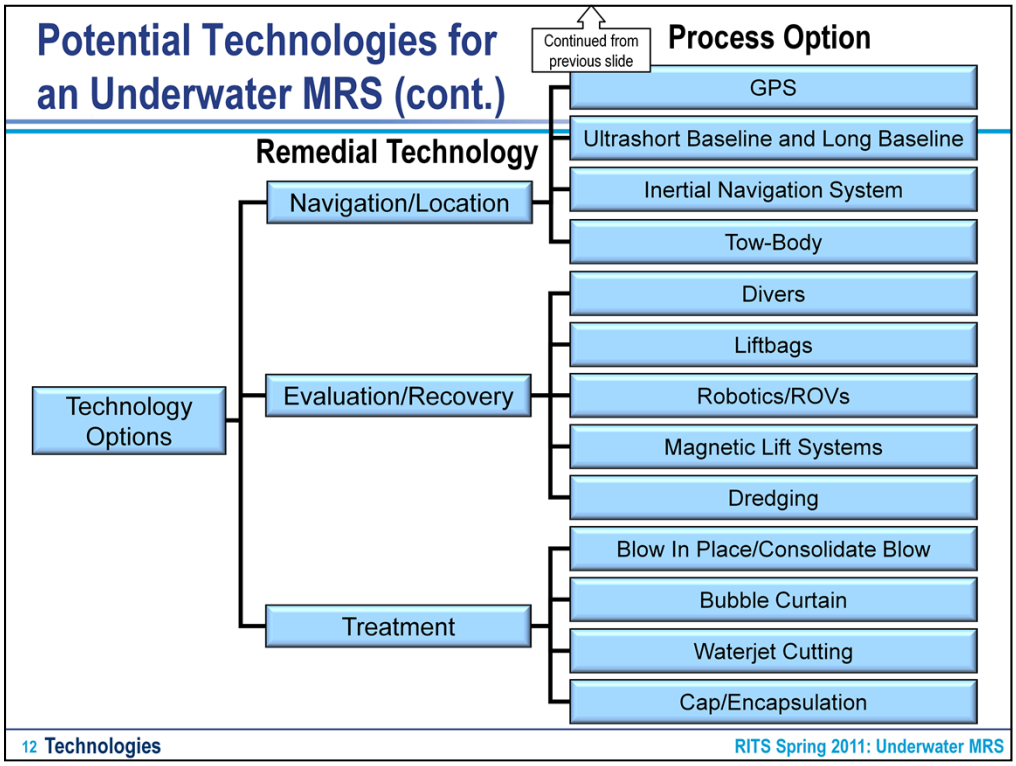
- There are **rules** to selecting a diver – he/she must be a DOD certified diver, **AND** NOSA requires documentation and time to approve the work plan prior to people going into the water.
- System is dynamicc – near shore items move (e.g., during the winter in San Diego, there is little sand but during the summer, there is a lot of sand). Sand is always moving – it is not a stagnant environment like terrestrial environments.
- **Must** determine the status of fuzing. If a fuse is present = unexploded ordnance (UXO). If there is not a fuse, it is a considered discarded military munitions (DMM).
- Fuses are very different. Some fuses are magnetic and encountering other metal can detonate them. Also, temperature can set off a fuse. Often, it's difficult to determine if a fuse is present because everything is corroded.



The technologies available are detection, platform, navigation/location, evaluation/recovery, and treatment.



- Selecting the right technology is critical because there is no standard application methodology, policy or guidance. The technology should be adapted to your site and typically a suite of sensors/technologies is used to understand the site.
- Sonar is the work horse.
- Magnetic systems can refine the sonar results.
- Detection systems can be mounted on an AUV or a ROV.
- A common combination first uses sonar, then a magnetic system, followed by a diver or ROV.



Navigation –It's best to use multiple methods to improve accuracy because there are lots of errors as everything is moving in the water.

- GPS does not work **under**water.
- Ultrashort baseline (USBL) can be used with towed sensor, but it's tricky to set up.
- Long baseline (LBL) set out beacons on land to determine where system is located, but noise on platforms can cause interference.
- Inertial navigation systems (INS) are accurate to within a few feet, but they are very expensive.

Evaluation/Recovery – less developed and more in R&D. Classification is the first step- is it UXO or junk?

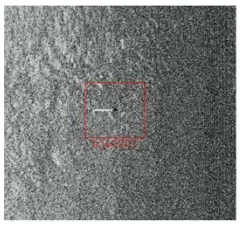
- A giant claw can pick it up.
- An ESTCP project is using a magnetic lift to pick up the UXO.
- Dredging the channel can remove everything, but it's expensive and stirs up the sediment.
- Divers are the standard method. They go down, pick up UXO, and carry (manually or via liftbags) to a barge.

Treatment - After determining if fused or unfused, then

- If fused, then need to mitigate problem of bowing up in place.
- Avoid carrying offsite to blow up.

Selecting the Right Technology

- Sonar – map the bottom
- Magnetometer – detect and map magnetic anomalies
- Diver or Video ROV – confirm the anomaly on the bottom
- Using a technology combination is required



Sonar
NOAA

Magnetometer
SAIC, Navy

Diver
NOAA

ROV
NOAA

13 Technologies RITS Spring 2011: Underwater MRS

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MEC Detection/Sonar

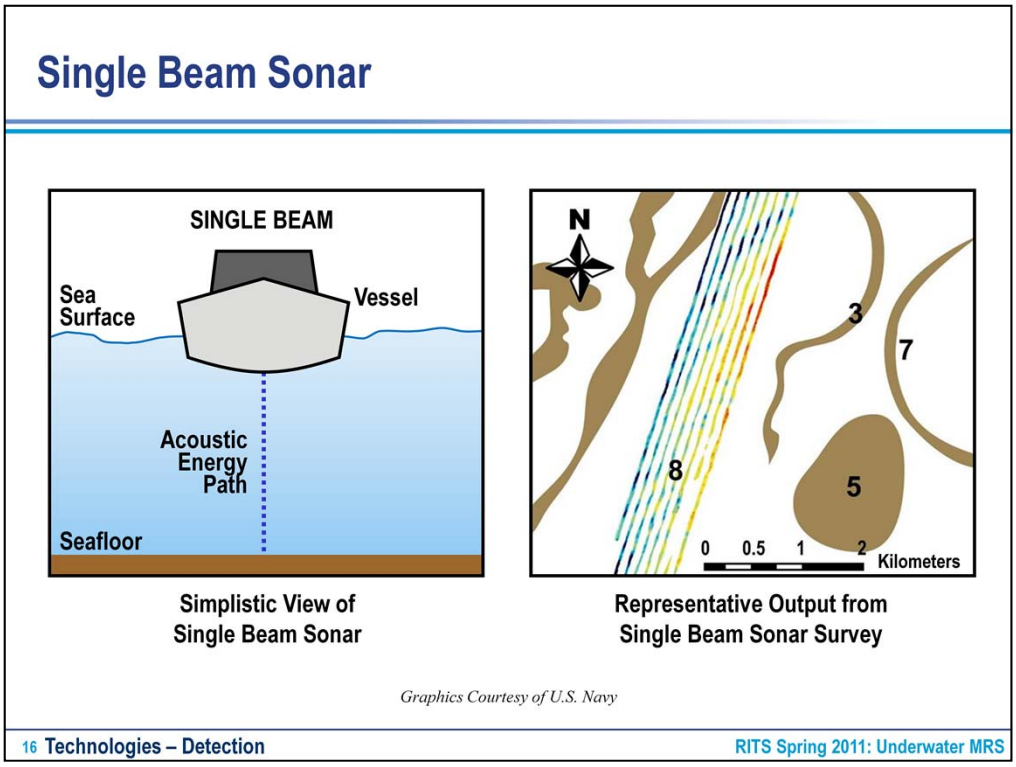
- **SONAR – SOund Navigation And Ranging**
- An underwater noise technique that uses sound propagation for navigation, communication, and detection
- Sonar types
  - Single Beam
  - Multi-beam
  - Interferometric
  - Side-scan
  - Imaging
  - Sub-Bottom Profiling
  - Synthetic Aperture

Side-scan Sonar Image of USS Monitor in 250' Depth off Cape Hatteras, NC
Image Courtesy of NOAA

15 Technologies – Detection RITS Spring 2011: Underwater MRS

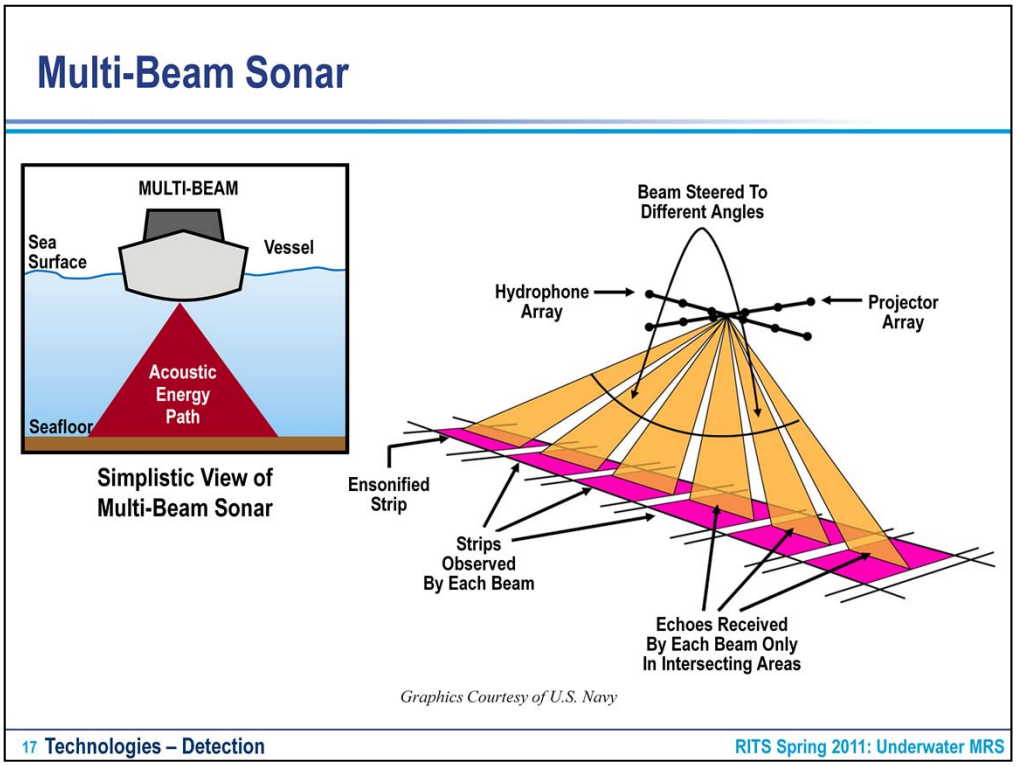
SOund Navigation And Ranging (SONAR)

- Use active sonar which can be include one of the types above.
- The portion of the acoustic wave that reverses its propagation direction after encountering an object (i.e., UXO or DMM) can be received by a remote transducer and exploited for acoustic remote sensing.



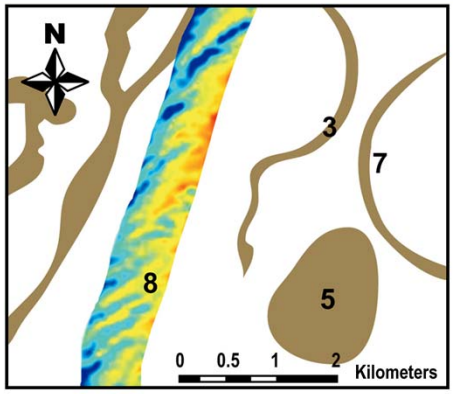
Single beam, Multibeam, and Interferometric sonar systems are used for bathymetric surveying (measuring water depth).

- In single beam systems, an acoustic pulse is emitted from a transducer downward toward the sea floor. Provides a single depth measurement for a location directly beneath the ship.
- Individual values of depth to the sea floor are subsequently contoured to generate bathymetric maps.



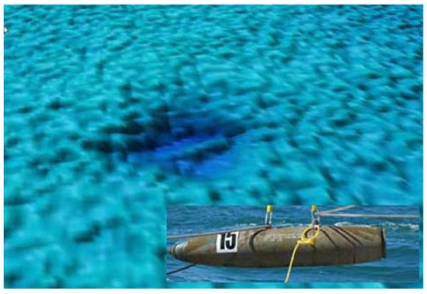
- Side-scan sonars do not produce information on the height of an object. Object height is an important piece of information required to map depths and identify objects.
- Swath sonars address the height issue by adding resolution using either a Mill's cross or Mill's T of an additional array. The geometry is identical to that of a standard side-scan sonar. Unlike a side-scan sonar, multibeam sonars use an independent array.

Multi-Beam and Interferometric Sonar



Representative Output from Sonar Survey

Graphic Courtesy of U.S. Navy

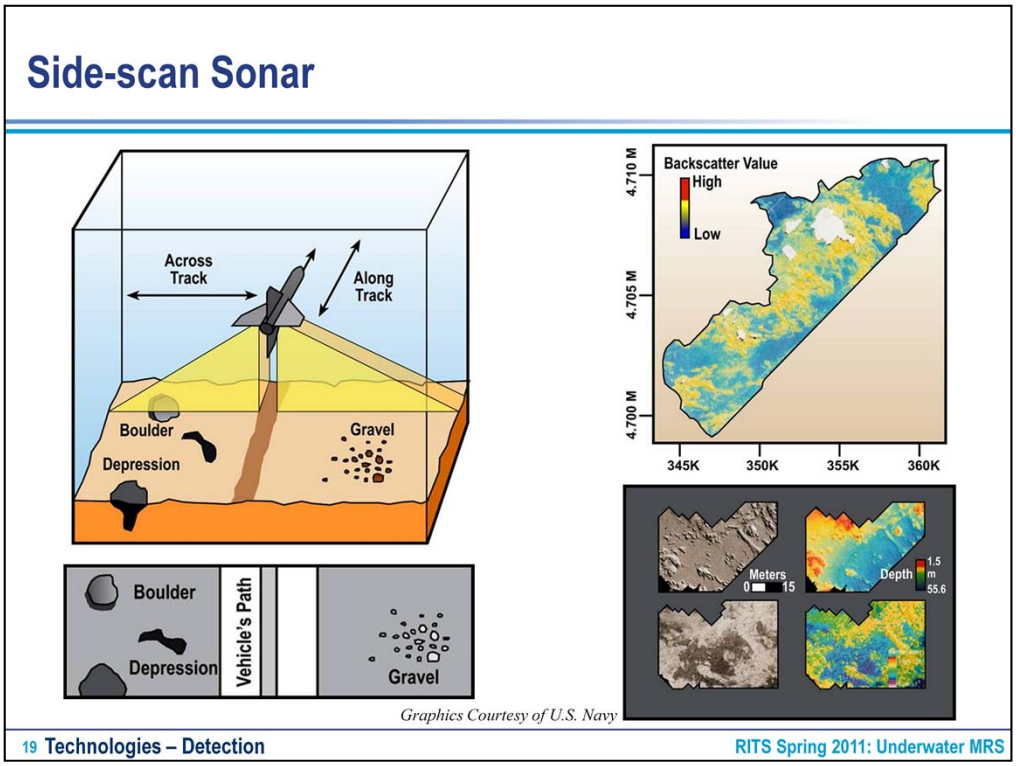


3D Multi-Beam Sonar Image of Tapered Bomb

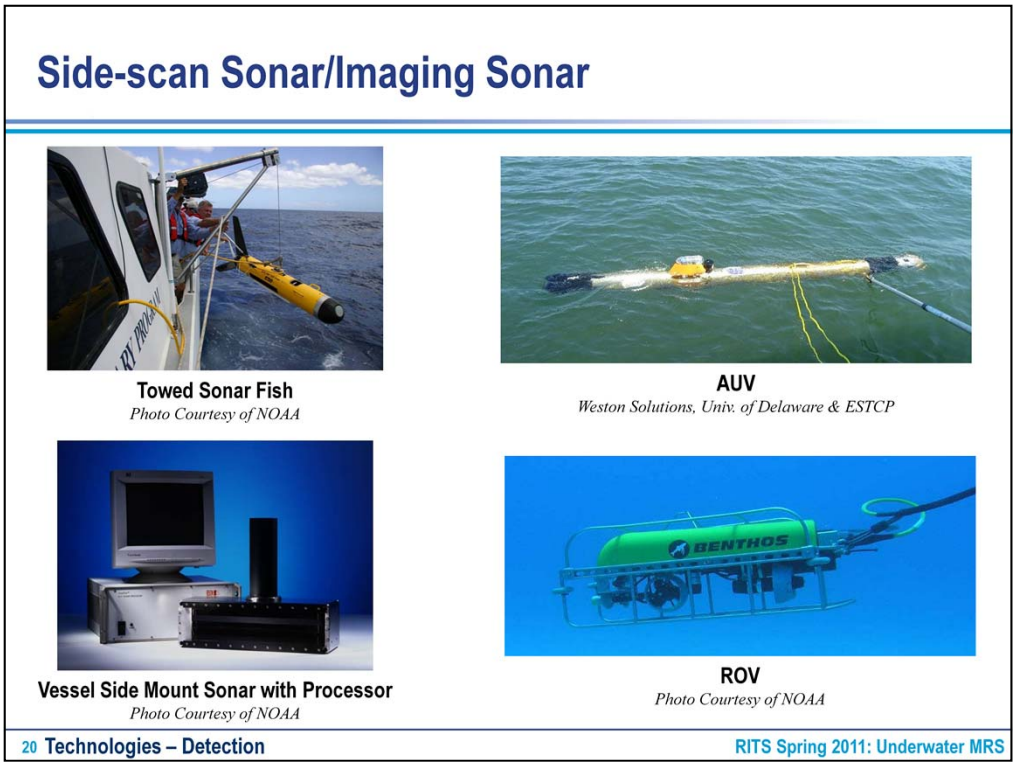
Image Courtesy of SERDP

18 Technologies – Detection RITS Spring 2011: Underwater MRS

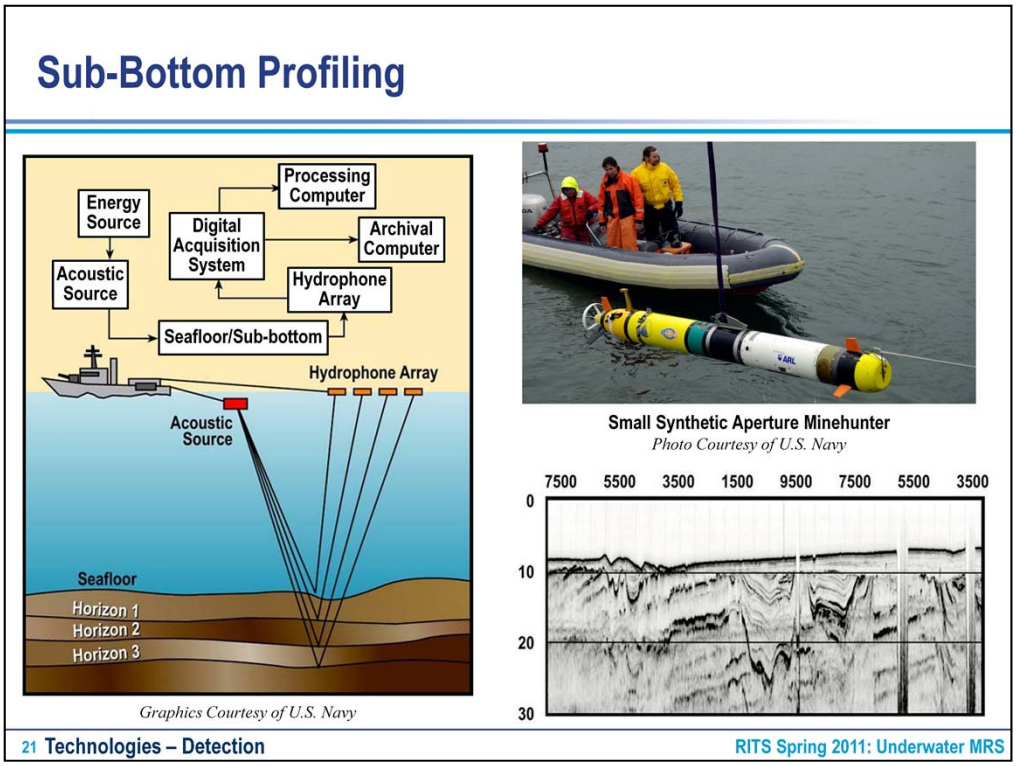
- With ITR sonar systems, the acoustic energy is propagated downward in a beam that is narrow in the along-track dimension and wide in the across-track dimension. This method produces a line of depth measurements across-track (i.e., perpendicular to the research vessel's trackline). As the vessel moves forward, these profiles sweep out a ribbon-shaped surface of depth measurement, known as a swath.
- Depth measurements from ITR systems are obtained by measuring the angles of the incoming sound signals in addition to the range. ITR sonar systems require three or more linear arrays of transducer elements, or staves, one to transmit acoustic energy and at least two to receive the returning signal. By contrast, the sidescan sonar systems can be operated to transmit and receive on the same array of transducers.
- The ITR sonar system measures depth using both the travel time of the emitted pulse and the angle the returning sound energy makes with each linear array or stave. Both sets of data make it possible to determine the exact location from which the scattered returning energy originated.
- Lower operational frequency provides higher range but lower resolution.



- Side-scan sonar technology is used to search for and detect objects on the seafloor. For example, shipwrecks are commonly found and mapped using side-scan sonar.
- Side-scan sonar requires three components—a towfish that sends and receives acoustic pulses, a transmission cable attached to the towfish that sends data to the ship, and the ship's processing computer. The found object or seafloor feature can be plotted/visualized.
- The acoustic pulse is specifically designed such that it is wide in the across-track direction and narrow in the along-track direction (depicted by the bright yellow fan-shaped area in the diagram).
- Side scan sonar continuously records the return echo, thus creating a "picture" of the sea floor. This picture is made up of dark and light areas. Hard objects protruding from the bottom send a strong echo and create a dark image. Shadows and soft areas, such as mud and sand, send weaker echoes, thus creating a light image.
- In the schematic to the right, strong reflections (high backscatter) from boulders, gravel and vertical features facing the sonar transducers are light gray; weak reflections (low backscatter) from finer sediments or shadows behind positive topographic features are dark gray.



- A sonar image will always have less resolution than an optical image, due to the nature of the ultrasonic signals used to generate it.
- Photos of the different components of the side-scan sonar system.



- Seismic reflection profiling is accomplished by towing or mounting to the vessel, a sound source that emits acoustic energy in timed intervals behind a vessel. The acoustic energy is reflected from boundaries between various layers with different acoustic impedances (i.e. the water-sediment interface or between geologic units). The reflected signal is received either by a ship-towed hydrophone (or array of hydrophones) or with some CHIRP systems, by the same transducer array emitted the original sound. The reflected signal is converted to an analog signal which is digitized and logged. The data can then be processed and imported to computer mapping programs for interpretation.
- CHIRP (Compressed High Intensity Radar Pulse) techniques have been used for years above the water in many commercial and military RADAR systems. The techniques used to create an electromagnetic CHIRP pulse have now been modified and adapted to commercial acoustic imaging sonar systems.
- The higher frequencies of operation provide the highest resolution, but are limited in amount of penetration below the sea floor. The lower frequencies yield more penetration, but less resolution.
- Questions to ask to help guide selection of equipment:
    - What are potential sediment types and geologic units? What is the maximum stratigraphic depth that is relevant to the particular study? This aids in determining the appropriate system to use.
    - If little information is available to us, we will operate multiple seismic-reflection systems simultaneously. The objectives and survey environment will dictate system choice.
    - One consideration is always the trade-off between range, or penetration, and resolution. In the marine, lacustrine, or estuarine environments, the best source is determined primarily by the water depth and the type of sediments/rocks in the substrate.
    - Logistical parameters (e.g. cost, boat size, noise, time available, number of crew available, weather, environmental factors (ambient noise, ship traffic, etc.) enter into the decision as to which system(s) will be utilized for a given survey.

Marine Mammals and Sonar

- **Natural sonar – "Biosonar"**
  - **Echolocation used for navigation, location, feeding, mating, defense and communication by marine mammals**
- **Concern about Survey Sonar and Marine Mammals**
  - **Common pingers operate in the 20KHz to 32KHz range**
  - **Common bathymetric and imaging sonars operate between 100KHz and 1MHz**
  - **Not considered harmful to marine mammals**
    - Low Power and/or
    - Above hearing range
    - Not a regulatory issue but do give courtesy notice to the stakeholders

Photo Courtesy of NOAA

22 Technologies – Detection RITS Spring 2011: Underwater MRS

If sonar is used, ensure SOPs are written and the system is calibrated and checked every day. Make sure that everyone is following the rules because if a dolphin washes up on shore, there could be questions.

Sonar Pros and Cons

- **Single beam**
  - Widely available and inexpensive boat safety device
  - Does not produce data of sufficient quality for MEC work
- **Multi-beam/Interferometric**
  - Widely available and inexpensive
  - Produces high resolution bathymetric data that can be used for follow on surveys and may detect proud MEC
- **Side-scan**
  - Widely available and inexpensive
  - Generates high resolution image of seafloor that may detect proud MEC
  - Cluttered environments such as coral, rocks, and vegetation can affect the ability to identify MEC like objects
  - Newer systems now map under the towfish/sonar

Sonar Pros and Cons (cont.)

- Visual/Imaging
  - Widely available and inexpensive
  - Water clarity limits effectiveness of visual
  - Imaging sonars have a shorter range but higher resolution than side-scan and Multi-beam
- Sub-bottom profiling
  - Defines different sediment layers that help identify where a MEC item may be buried
  - MEC items can often be too small to identify with technology
- Synthetic aperture
  - Not widely available, still mostly developmental
  - Able to detect partially buried objects

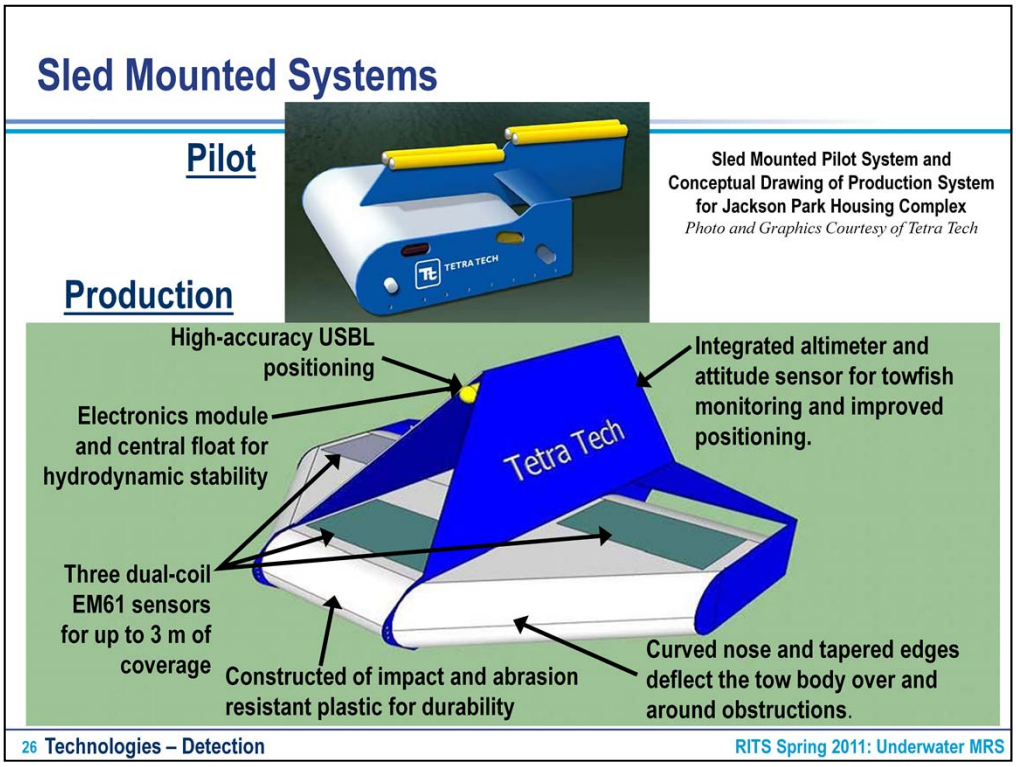
MEC Detection/Mag and EM

- Magnetometers and electromagnetic induction
  - Diver handheld instruments
  - Towed arrays
  - Sled mounted systems
  - Aerial systems

ESTCP-Sponsored Demonstration of SAIC's Underwater Multiple Towed Array
Photo Courtesy of ITRC

25 Technologies – Detection RITS Spring 2011: Underwater MRS

- Physics of how Mag and EM detectors work is not affected by being underwater.
- Deployment of the detector system is however different. Deployment can be made by towed systems which "fly" off the bottom. Sled mounted systems have also been developed.
- Here is a picture of the system tested by ESTCP and used a Jackson Park.



- For the pilot study, system surveyed 2.6 acres.
- After learning some lessons, a production survey system was developed (lower picture).

Mag/EM Induction Pros and Cons

- Well-developed technology suitable for detecting metals
- Detection is a function of distance and size of item, not whether the item is proud or buried
  - Systems must be as close to the bottom as is feasible
- Towed platforms can snag on bottom obstructions
- Wide area survey technologies do not typically detect smaller MEC items
- Limited production rate with handheld systems
- Expensive in comparison to other survey technologies
- Requires data post processing unless using a diver handheld instrument
- Does not differentiate whether the item is MEC or other metal debris

27 Technologies – Detection RITS Spring 2011: Underwater MRS

- Can be hand held e.g. guys looking for coins on the beach.
- Some that can be used under water (e.g., diver hand held, towed on small boat, and sled mounted).
- Aerial systems are available but are not good for underwater.
- Towed platforms may snag on debris in the water so do a side-scan survey first. Then, a more sensitive for mag/EM survey can be done.
- Not good at differentiation munitions from junk or debris. There can be lots of debris in bays.

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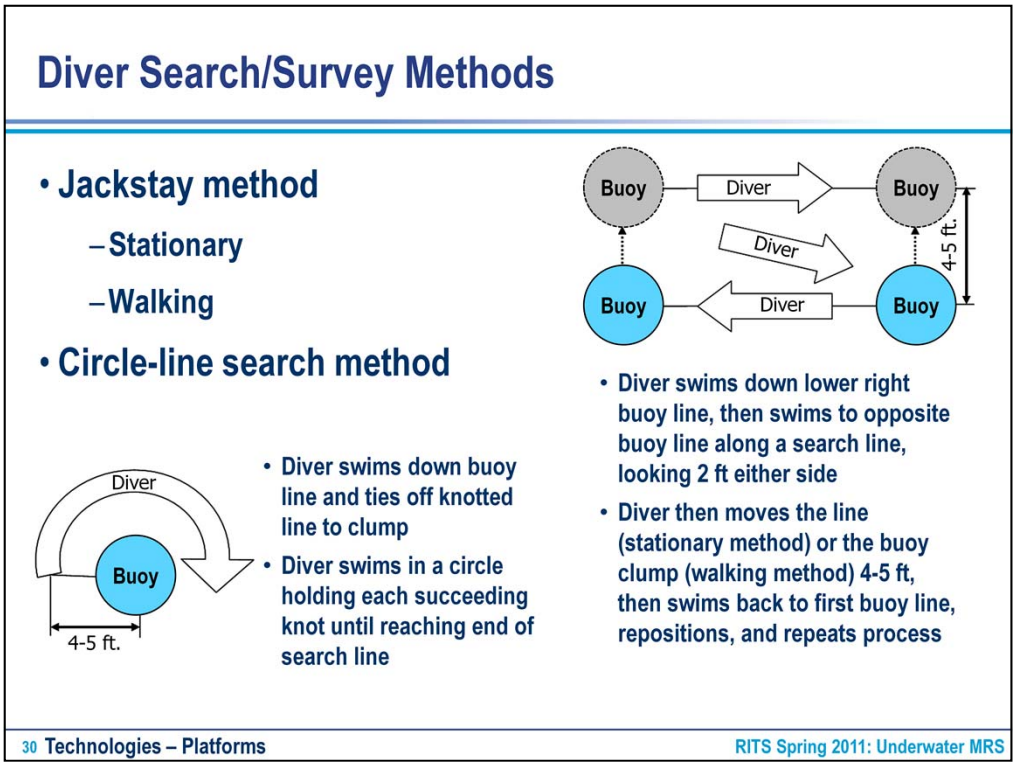
Platforms

- In order to make measurements to determine whether there is MEC or not, some type of platform must be used
  - Divers
  - Remotely operated vehicles (ROVs)
  - Autonomous underwater vehicles (AUVs)
  - Vessels with or without towed systems
  - Supervised underwater vehicles (SUVs)

Diver Performing Seafloor Search
Photo Courtesy of U.S. Navy

29 Technologies – Platforms RITS Spring 2011: Underwater MRS

- If using divers, use fixed buoys so diver can swim from buoy to buoy in a circle or line.
- ROVs can be small or can be truck size. Taylor your choice to need you have.
- AUVs is currently main area of research and development. An AUV has to carry all their power on board so may run out of power quickly. Good for areas where diver cannot go into easily.
- Divers are highly maneuverable but usually grumpy, limited dive time.
- Overall, ROVs are the work horse and are relatively cheap. Limited in power but ineffective at very shallow and strong currents.

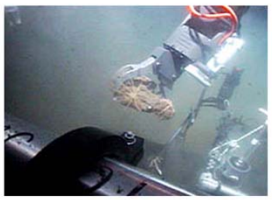


- The most proven method of conducting underwater remedial investigation is using divers, especially when the seafloor is irregular.
- Munitions are buried under sediments or encrusted. Munitions can be in kelp beds.

ROVs

- ROVs are typically controlled and powered from the surface by a tethered line
  - Micro, mini, and workclass ROVs
  - Sonar, magnetometer, and video equipped
  - Some with manipulator arms

VideoRay ROV
Photo Courtesy of U.S Navy



Manipulator ROV
Photo Courtesy of WHOI

U.S. Navy's Unmanned Vehicle "Deep Drone" Recovers a Piece of the Tail Section from Alaska Air Flight 261, Aboard M/V Independence
Photo Courtesy of U.S Navy

31 Technologies – Platforms RITS Spring 2011: Underwater MRS

- A remotely operated vehicle (ROV) is a tethered underwater robot.
- Common in deepwater industries such as offshore hydrocarbon extraction.
- ROVs are unoccupied, highly maneuverable and operated by a person aboard a vessel (on the surface).
- They are linked to the ship by a tether (sometimes referred to as an umbilical cable), a group of cables that carry electrical power, video and data signals back and forth between the operator and the vehicle.
- Most ROVs are equipped with at least a video camera and lights. Additional equipment is commonly added to expand the vehicle's capabilities. These may include sonars, magnetometers, a still camera, a manipulator or cutting arm, water samplers, and instruments that measure water clarity, light penetration and temperature.

AUVs

- AUVs can be thought of as robotic submarines and can carry a wide array of payloads
  - Fly-by data collection using depth sensors, sonars, magnetometers, thermistors, and chemical sensors
  - Range in size from cm to m
  - Powered by rechargeable batteries
  - Ultra low power gliders being developed

ONR's XRay Underwater Glider
Photo Courtesy of U.S. Navy

AUV Mine Clearing in Iraq
Photo Courtesy of U.S. Navy

32 Technologies – Platforms RITS Spring 2011: Underwater MRS

Recently there has been a breakthrough in the use of the different temperature profiles in the ocean to recharge the gliders batteries, thus allowing the possibility of greatly extended missions.

Platforms Pros and Cons

- Diver
  - 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
  - High cost per acre surveyed
- ROV
  - Variety of sensors available and larger systems have manipulators which 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
- AUV
  - Autonomous predetermined survey pattern that doesn't require constant monitoring
  - Limited power supply for sensors and a limited sensor array
  - Difficult to monitor progress during mission due to limited bandwidth UW
  - Ineffective in high current/surge type of environment due to low speed

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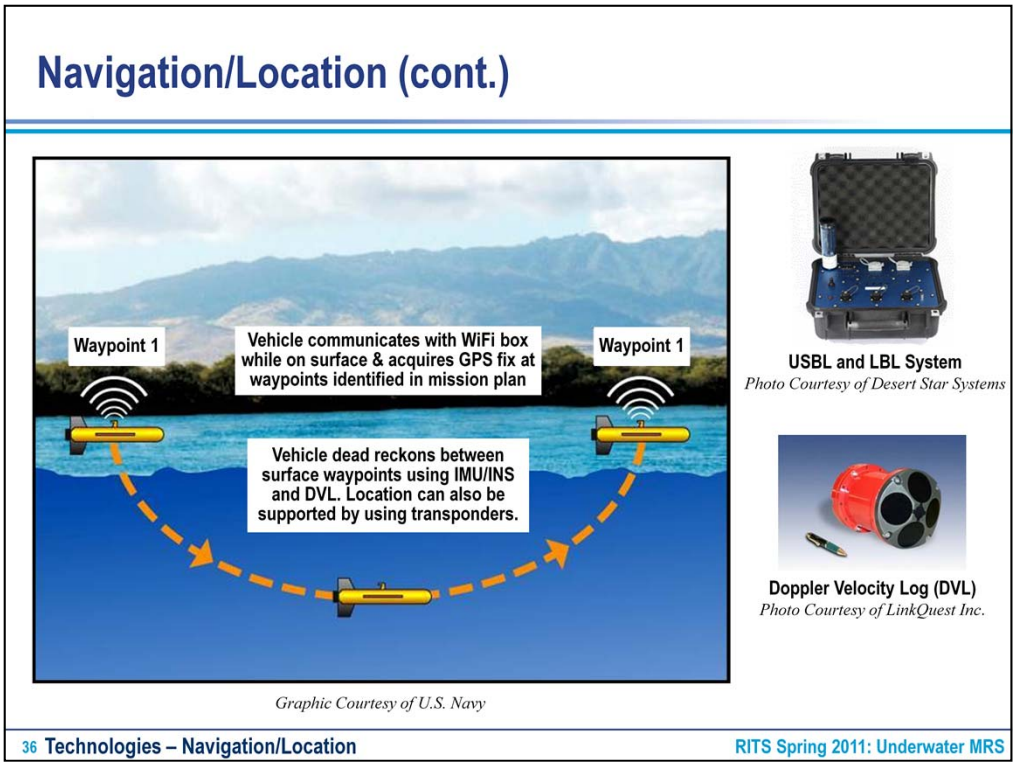
Navigation/Location

- **Navigation is the process of planning, recording, and controlling the movement of a craft**
  - **GPS with real-time kinematic (RTK) control**
  - **Ultrashort baseline (USBL) and long baseline (LBL)**
  - **Inertial navigation system (INS) with doppler velocity log**
  - **Tow Cable Lay-Back**

Handheld Navigation Unit and GPS Constellation
Photo and Graphic Courtesy of U.S. Navy

35 Technologies – Navigation/Location RITS Spring 2011: Underwater MRS

- Remember that GPS doesn't work underwater, but that it can be part of underwater navigation solution. With RTK, determination of range signal can be resolved to a precision of less than 10 cm (4 in).
- An inertial navigation system (INS) is a navigation aid that uses a computer, motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculate 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.
- 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.
- 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", calculates a position from the ranges and bearings measured by the transceiver. To calculate a subsea position, the USBL calculates both a range and an angle from the transceiver to the subsea beacon.



Here is an illustration of an AUV using GPS, IMU/INS and DVL to determine position while at the surface and underwater. DVLs collect, compile, and process velocity, heading, altitude, pitch and roll.

Navigation/Location Pros and Cons

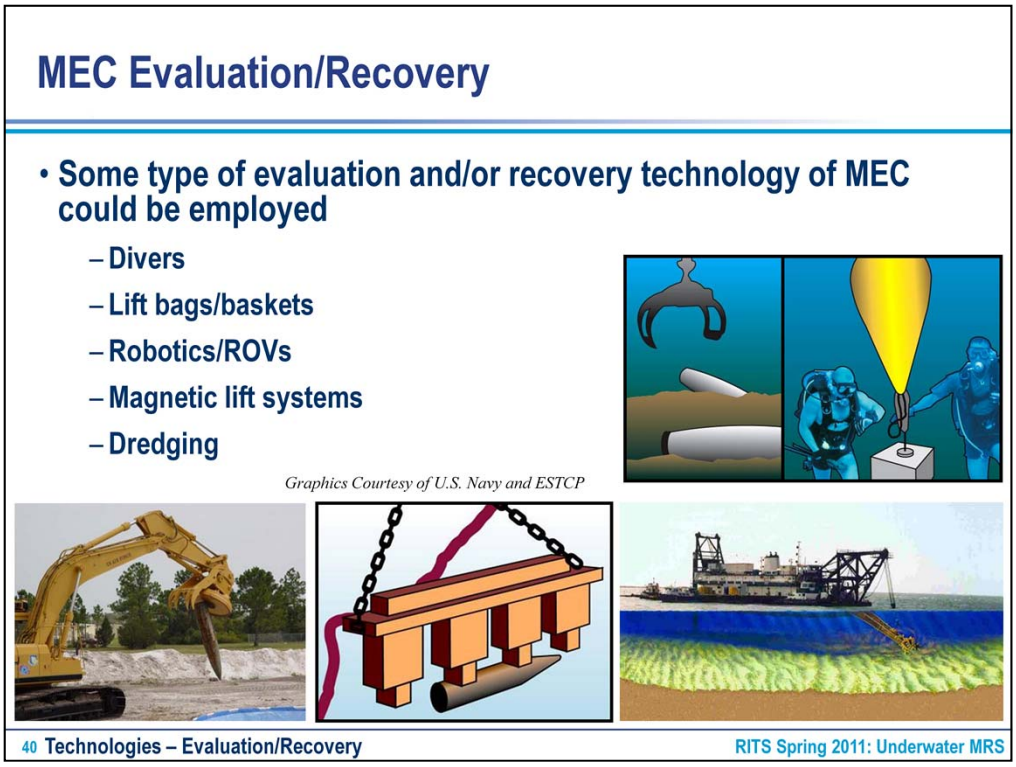
- GPS
  - Highly accurate but since the signal does not transmit underwater it is typically coupled with other technologies to increase overall accuracy
  - Rough sea surface can degrade accuracy
- INS
  - More accurate systems are "tactical grade" which are very costly
  - Loses accuracy over time/distance requiring periodic correction
  - AUVs slow speed typically require a DVL as well for increased accuracy
- Tow-Body
  - Inclinometer is typically coupled with GPS and USBL to increase accuracy

Navigation/Location Pros and Cons (cont.)

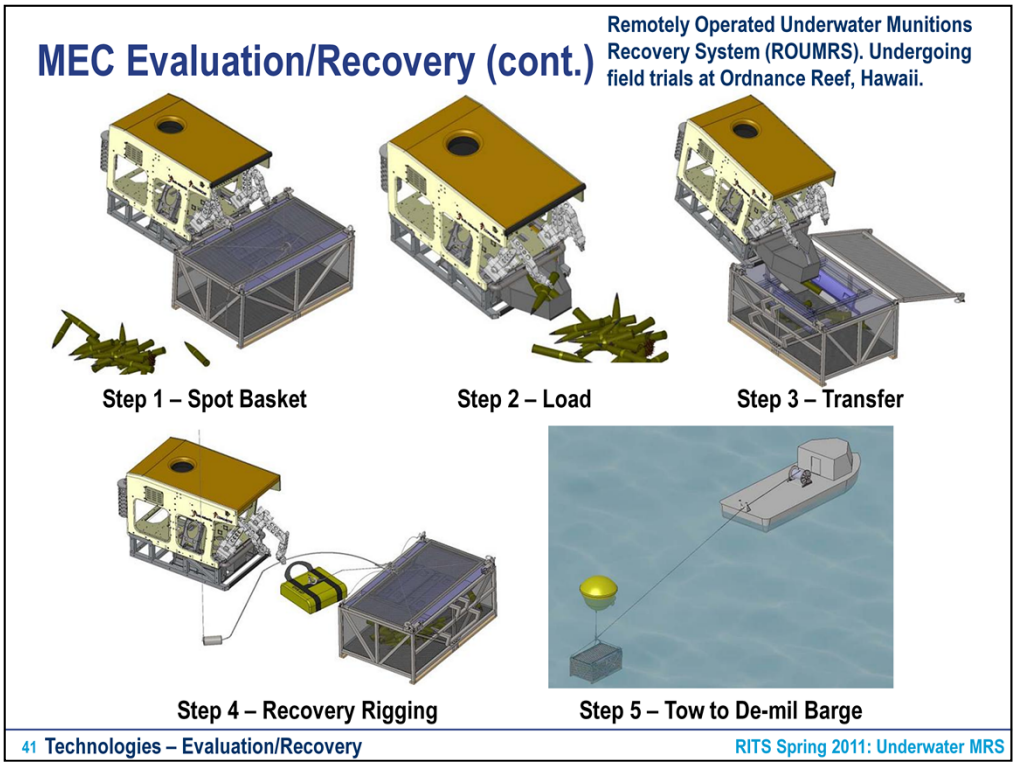
- USBL and LBL
  - LBL requires setup of an array of beacons and must be periodically repositioned.
  - USBL does not require the setup of an array of beacons but is not as accurate as LBL. It also requires careful installation and calibration for accuracy.
  - High ship noise areas (harbors) can require a more accurate positioning system such as LBL.
  - Rough terrain can reduce accuracy of LBL beacons due to influence of currents.

Presentation Overview

- Policy
- Underwater MRS Characteristics and Challenges
- ► Technologies to Investigate and Remediate a MRS
  - Detection
  - Platforms
  - Navigation/Location
  - Evaluation/Recovery
  - Treatment
- Munitions Constituent (MC) Toxicity and Munitions of Explosive Concern (MEC) Mobility Model
- Case Studies
- Summary



- A lifting bag is an air-tight bag with straps that lifts objects underwater by means of the bag's buoyancy. Bags can either be moved horizontally underwater by the diver or sent unaccompanied to the surface. The shape of the bag should distribute the volume in a vertical so that the open end of the bag always remains underwater. If the open end reaches the surface, air will escape from the bag and it may re-descend. A partially filled bag will accelerate as it ascends because the air in the bag expands as the pressure reduces on the ascent which increases the bag's buoyancy. It is advisable to select a lift bag with an appropriate capacity for the task at hand otherwise a grossly oversized bag may result in a runaway or otherwise out of control ascent.
- Dredging can be used to clear areas with high anomaly densities. Dredging is an excavation operation usually carried out at least partly underwater, in shallow seas or fresh water areas with the purpose of gathering up bottom sediments and disposing of them at a different location. This technique is often used to keep waterways navigable. Appropriate screening is also necessary to remove any MEC.
- The Magnetic UXO Recovery System (MURS) was tested by ESTCP. It consists of a robotic excavator retrofitted w/an electromagnet. The electromagnet could be useful for shallow water, soil surface, and potentially subsurface UXO recovery. Underground removal will be addressed by coupling conventional excavation processes onto the magnet and using the AOE to scrape the ground surface. MURS would be capable of remote operation, potentially saving multiple man years per site. It is expected to be capable of removing UXO from shallow water (up to 15 ft deep) and lifting UXO from soil and sediment in the subsurface without hazard.
- Some companies have developed underwater cranes that could then use lift bags to remove multiple UXO.



Step 1 Spot Basket
- Landing site inspected for coral/live rock
- Salvage Basket lowered to bottom and released
- ROV positions Basket near concentrated UXO, un-pins and opens upper door

Step 2 Load
- Hopper is extended out of Recovery Skid
- UXO is documented (video, laser scaling)
- Manipulators/tooling used to pickup UXO
- Small debris vacuumed into Canister Filters
- Retract Hopper

Step 3 Transfer
- ROV transits to and lands on Salvage Basket
- Hopper extended, contents emptied, and Hopper retracted
- Canister Filters jettisoned and recovered
- ROV transits to next Recovery Site

Step 4 Recovery Rigging
- Air Lift Valise is lowered, ROV moves it to Basket
- Air Lift rigging and Tow/Recovery Line connected
- ROV turns ON air valve and inflates Lift Bag
- Salvage Basket ascends to surface

Step 5 Tow to De-mil Barge
- Small craft slowly tows basket to De-Mil Barge
- Tow Line is passed to De-Mil Barge and rigged to a deck winch for recovery
- EOD crew Unloads Basket
- Basket and Air Bag prepped for next deployment

Technology R&D

- Track the latest in Underwater Munitions R&D Technology through SERDP-ESTCP
  - Take advantage of technology demonstrations at your underwater UXO site
  - Free data and report in exchange for using your site for the demonstration
  - Impress the stakeholders

Photo Courtesy of Weston Solutions, ESTCP, Univ. of Delaware

Evaluation/Recovery Pros and Cons

- Lift Bags
  - Item must be determined safe to move
  - Simple and inexpensive technology but it does require the use of divers
- Robotics/ROVs
  - Increased safety due to remote operation
  - Limited number of suppliers
  - Size limitations
  - High capital cost for robotics, which also require periodic repositioning
  - Larger ROVs require larger support vessels with increased costs
- Magnetic Lift System
  - Limited availability and limited field testing
  - Requires accurate remote positioning
  - Near direct contact of MEC is required
- Dredging
  - Covers wide area and can remove subsurface items
  - Subjects items to a high amount of energy
  - High cost with a very limited number of suppliers
  - Extreme impact to local benthic community and temporary impact to water quality due to suspended sediments

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MEC Treatment

- In order to determine your treatment options, you must first consider whether the MEC is UXO or DMM
  - UXO (fuzed, armed)
  - DMM (unfuzed, unarmed)
- Then consider your options
  - Blow-in-place (BIP) (high order)
  - Consolidate and blow
  - BIP (low order)
  - Bubble curtain
  - Covers
  - Abrasive water jet cutting
  - Encapsulation
  - Capping

Photos Courtesy of U.S. Navy, NMFS

45 Technologies – Treatment RITS Spring 2011: Underwater MRS

And finally, you have to dispose of the item. Here are your options. We will go over the bubble curtain technology in the last topic.

Regulatory Drivers for Underwater Investigation and Treatment

Main Regulatory Drivers for Underwater MRSs

- Clean Water Act
- Endangered Species Act (ESA)
- Marine Mammal Protection Act (MMPA)
- Magnuson Stevens Fisheries Conservation Act
  - Essential Fish Habitat (EFH)
- Consultation with NMFS required for ESA, MMPA, and EFH
  - Mitigation required but can be varied
  - Avoidance of species and habitats
  - Seasonal migration
  - Operational avoidance, bubble curtains, etc.

2,000-lb UXO Resting on T&E Staghorn Coral

Photos Courtesy of U.S. Navy

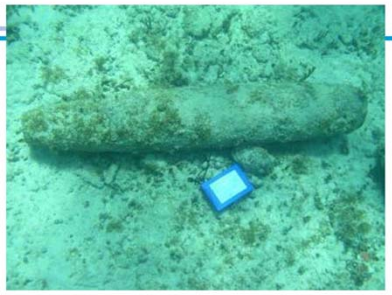
46 Technologies – Treatment

RITS Spring 2011: Underwater MRS

Regulatory drivers. Basically, if there is an act with water in the name it should be paid attention to.

BIP/Consolidated Shots

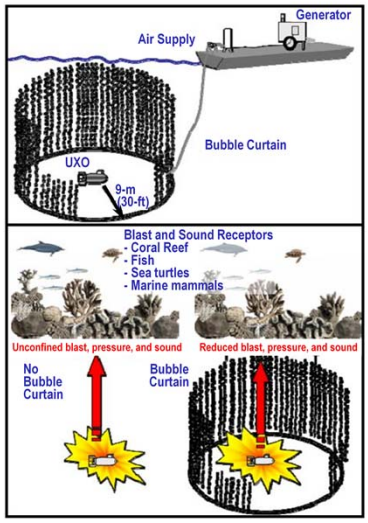
- **BIP disposal must consider:**
  - **MEC Type**
    - UXO (fuzed, armed)
    - DMM (unfuzed, unarmed)
  - **Safety Considerations/Safe to Move**
  - **Overpressure/Blast Effects**
  - **Sympathetic Detonation**
- **Consolidated Shots have the same considerations but on a larger scale**
- **Human safety and habitat taken into consideration**



Photos Courtesy of U.S. Navy

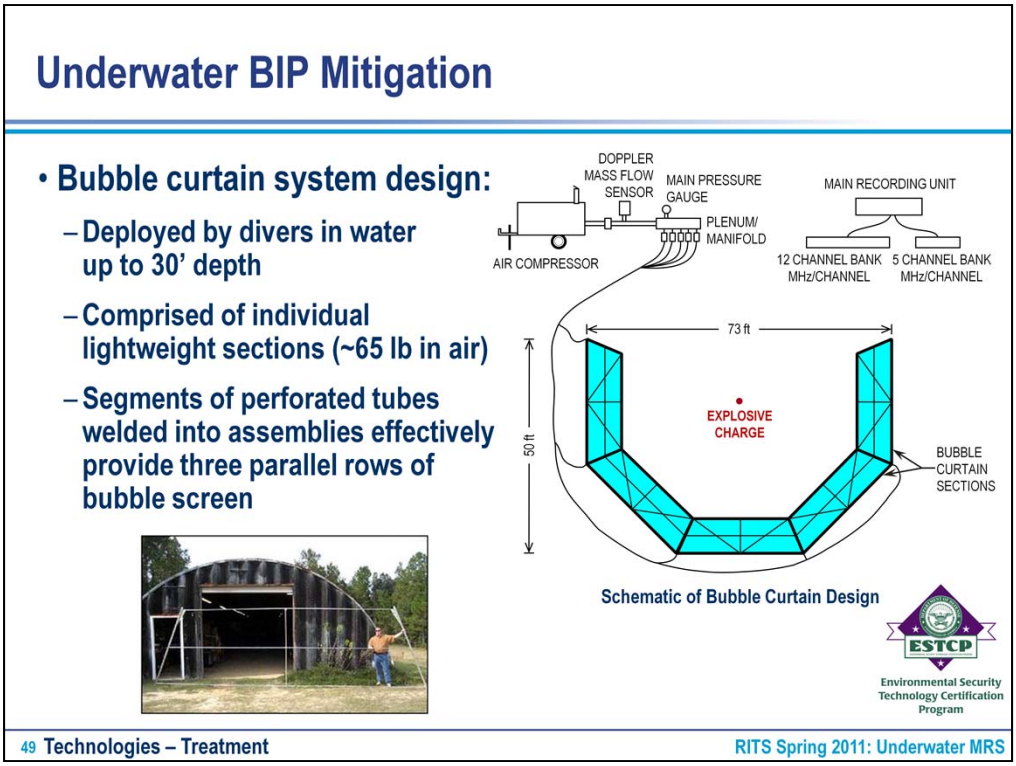
Bubble Curtain

- Bubble curtains are mitigation technology to augment UXO treatment by BIP
- Bubble curtains are designed to reduce pressure waves and noise from UXO BIPs to protect marine life
- Bubble curtains required by National Marine Fisheries (NMFS) to mitigate offshore oil platform demolitions and underwater pile driving
- Navy has developed a successful R&D prototype for large military ordnance
  - Searching for a field site to fulfill ESTCP field demonstration requirement



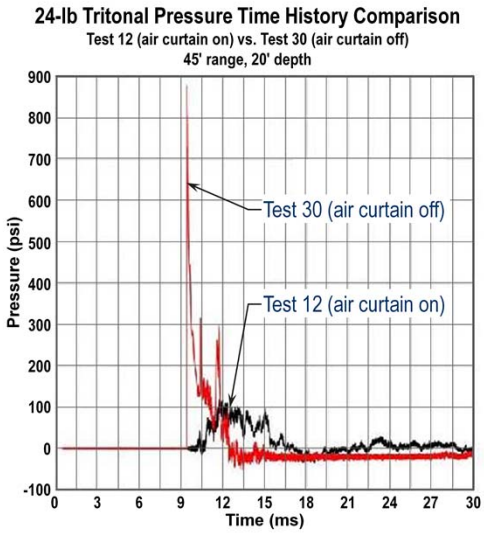
48 Technologies – Treatment RITS Spring 2011: Underwater MRS

- The power of the blast should be considered.
- National fisheries is also involved.
- Avoid seasons when specific species (e.g., fish, turtles, etc.) travel.
- May need to move munitions downstream before blowing it up.

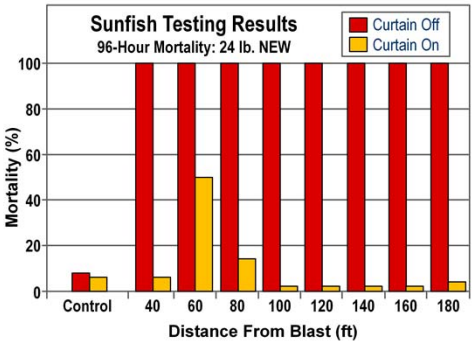


- A bubble curtain or blanket can mitigate blast.
- A bubble curtain creates bubbles so there is a change in density between the water. The change in density acts like a muffle that mitigates blast effects.
- Place PVC pipe with holes around the munitions, pump air into PVC, then blast munitions.
- Typically, blast does not go beyond curtain. Bubble curtains are cheap and work.

Underwater BIP Mitigation (cont.)



- **Air curtain reduced peak pressure by 87%**



50 Technologies – Treatment RITS Spring 2011: Underwater MRS

- Bubble curtain test reduced the peak pressure by an average 54-95% depending the net explosive weight (NEW)
- The pressure impact radius was also reduced by an approximately 99% for a 24lb charge
- Fish mortality was reduced by 94% for a 24lb charge
- The bubble curtain survived blasts up to and including a 24lb NEW as well as one MK 82 blast.

Unmitigated BIP

- Unmitigated BIP – before and after

Before

After

Photos Courtesy of NOAA

Covering Technologies

- R&D development of underwater blasting mats to mitigate noise, shockwave, and fragmentation
- Blasting Mat for mitigating BIP frag
  - Wire mesh design
  - For use in shallow waters near populated areas
  - Can be used in conjunction with bubble curtain

Photos Courtesy of U.S. Navy

Treatment Pros and Cons

- BIPs/Consolidated Shots
  - High order BIPs/Consolidated shots are chemically very efficient reactions
  - Low order BIPs result in release of MC into environment
  - Localized impact to the environment from detonation
- Bubble Curtain
  - Limits area of environmental impact from blow-in-place
  - Simple to implement
  - Not effective in shallow restricted water due to reverberation and small space
- Water Jet Cutting
  - Limited availability
  - Containment of debris
  - Shell left in place
- Cap/Encapsulation
  - Can remediate difficult to recover UXO
  - Requires periodic monitoring to make sure it is still effective
  - Environmental concerns with leaving item

53 Technologies – Treatment RITS Spring 2011: Underwater MRS

- There are safety zones for fish and for recreational divers which is typically very large.
- Stainless steel mesh blanket can be used together with the bubble curtain to dampen the blast effect. It is relatively inexpensive as well.
- Low order blow in place releases constituents in water and shell is left typically done when no fuse present. High order munitions.
- Capping the area or encapsulating the munitions is possible but cap must be monitored.

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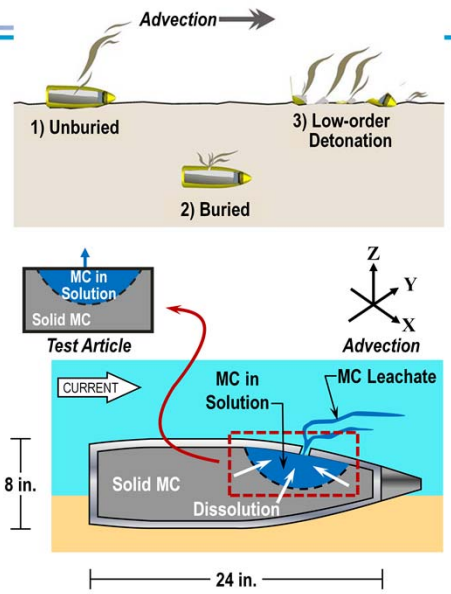
Underwater MC Ecological Risk

Common Energetic Fill Materials

- **TNT**
  - **TNT transformation products**
    - 2ADNT
    - 4ADNT
    - 2,4DANT
    - 2,6DANT
    - 2,4 DNT
    - 2,6DNT
    - Trinitrobenzene (TNB)
    - Dinitrobenzene (DNB)
- **RDX**
- **HMX**



Images Courtesy of U.S. Navy

Underwater MC Ecological Risk (cont.)

Laboratory Investigations

- TNT has limited persistence
- TNT binds readily with sediments
- TNT and RDX degrade rapidly in sediments
- HMX mineralizes in sediments
- TNT and RDX approached steady concentrations much lower than maximum attainable concentrations
- Sediment microorganisms are capable of degrading both RDX and HMX
- TNT, RDX and HMX are low in toxicity and do not bioaccumulate
- Laboratory exposures cannot be achieved in natural environment because of fate and undetectable concentrations
- Environmental risks associated with energetic fill are likely negligible

Sheepshead Minnow and Chunk of RDX
Photo Courtesy U.S. Navy

56 MC Toxicity and MEC Mobility Model RITS Spring 2011: Underwater MRS

- Toxicity of Munitions Constituent – common constituent TNT, RDX and HMX.
- Several models have been done to determine how long it takes for the toxic components to leak out of the munitions. Laboratory studies state that environmental risks are likely negligible.
- Field investigation sampling tissues of fish in all sites states that it is probably not a problem because it has not been found in fish.

Underwater MC Ecological Risk (cont.)

Field Investigations

Photo Courtesy of J. Noles

- Vieques fish tissue sampling resulted in MC non-detects
- ATSDR public health risk assessment for Vieques and Marianna Islands' seafood consumption concluded no risk
- NOAA random sampling of Vieques and Ordnance Reef sediments and coral tissue resulted in MC non-detects
- Jackson Park sediment and fish tissue sampling resulted in MC non-detects
- Field MC ecological risk assessment methodology needs to be developed for regulatory acceptance

Underwater MEC Mobility Project

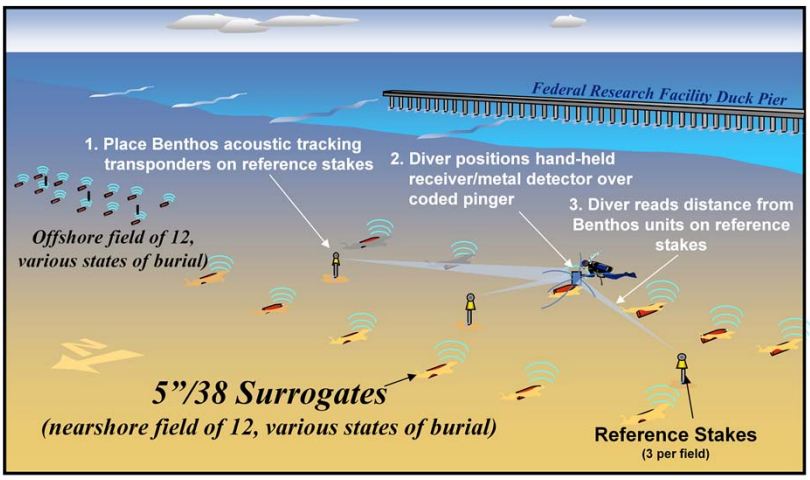
Photo Courtesy of U.S. Navy

- ESTCP Underwater UXO mobility model developed by NAVFAC ESC
- Field test calibrations conducted at two geomorphic coastal sites
- Predicts probability of migration of UXO from known areas of responsibility to adjacent areas of risk
- Substantial observed movement
  - Observation is consistent with migrating sandwaves
  - It suggests active movement during periods of exposure, despite the absence of any major weather events during measurements
- The tendency to move mostly parallel to the beach is consistent with model predictions
- Recently modified for Awa channels
  - Awa channels collect MEC, only re-deposited on the reef in large storms/hurricanes

58 MC Toxicity and MEC Mobility Model RITS Spring 2011: Underwater MRS

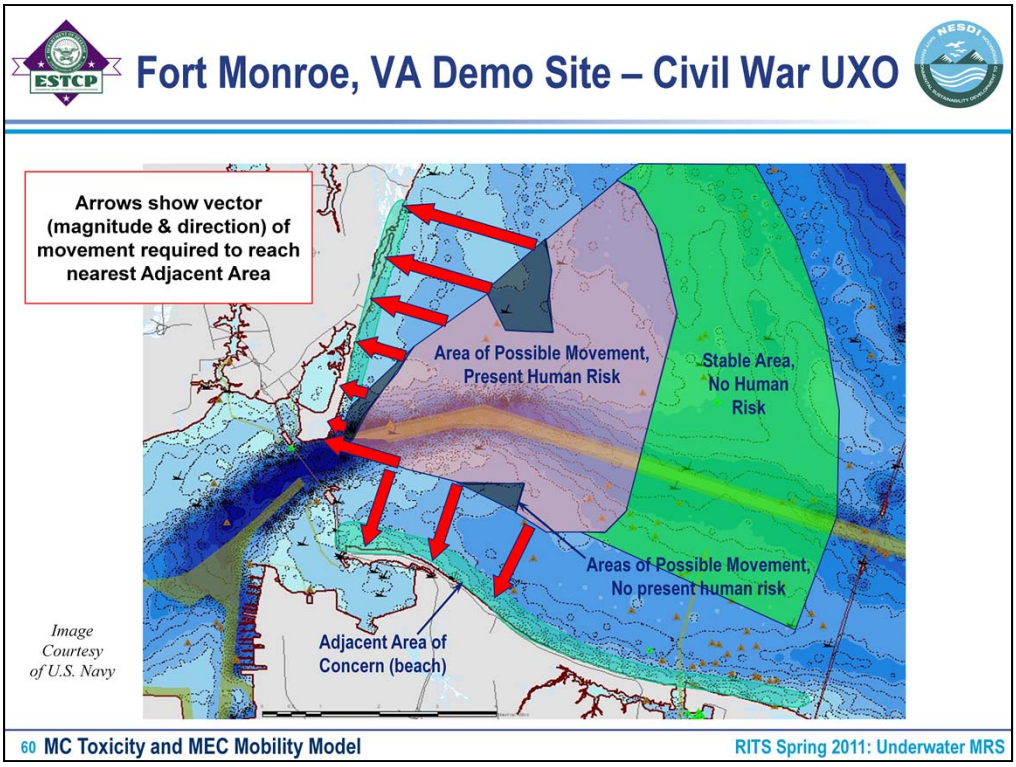
- Problems of underwater munitions- things move around.
- The way the system is you write a report, it gets approved, then you remediate a year or two later but it’s not good for underwater munitions because stuff moves around.

FRF Duck Measurement Method



Test Site in Duck, North Carolina Surf Zone

Image Courtesy of U.S. Navy



- Research has been done to figure out where the munitions are going.
- One demonstration set out a bunch of munitions simulators. Did they move together with the sand?
- Civil war munitions are washing up on the site study done to figure out what type of forces are involved so vectors for the wave actions show it pushing things up on the shore.

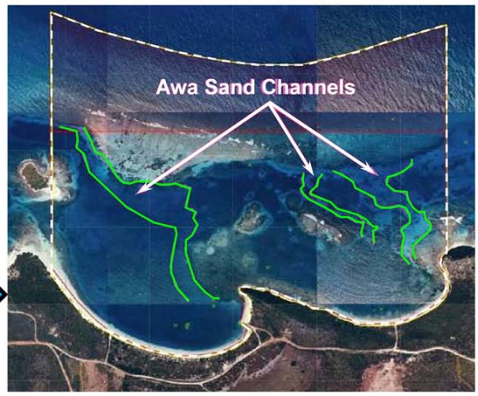
Oceanographic Conditions Influencing Underwater Mobility

Offshore wave surge channel into embayment

Vieques Underwater UXO Demonstration Project
Project Study Area: Bahia Salina del Sur

Near shore surface currents channel into shallow embayment

Vieques Underwater UXO Demonstration Project
Project Study Area (North): Bahia Salina del Sur

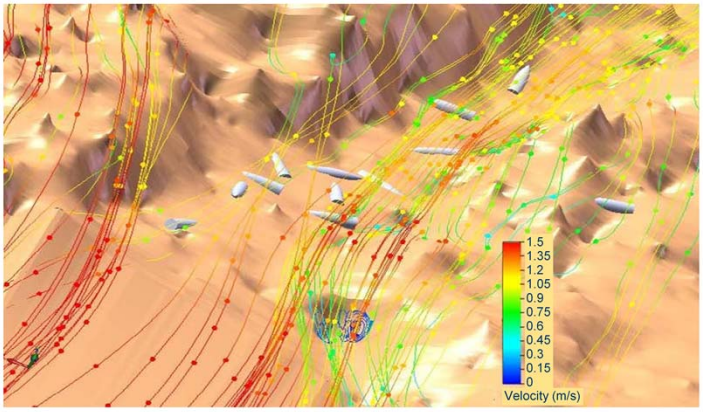


61 MC Toxicity and MEC Mobility Model

RITS Spring 2011: Underwater MRS

Oceanographic Conditions Influencing Underwater Mobility (cont.)

UXO Mobility Modeling
Vieques Island South Awa Sand Channels



- **Wave surge velocities scour bottom sediments to expose/bury UXO**

Image Courtesy of Scripps Institution of Oceanography at UC San Diego

62 MC Toxicity and MEC Mobility Model — RITS Spring 2011: Underwater MRS

- At Vieques, munitions fall into the sand channels and move along with the sand. On rocks they just move around then go to the sand channels.
- ESTCP sponsored a program to model where munitions are going.
- Results show they go into the sand channels with very little munitions on the coral reef.

Natural Mitigation Through Biogrowth

- **UXO safety mitigation through coral encrustation and sedimentation**

Photos Courtesy of U.S. Army

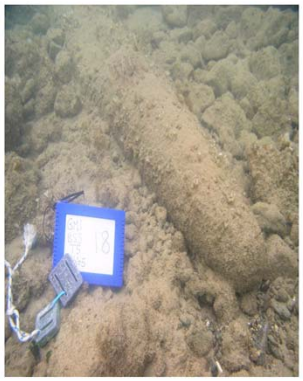


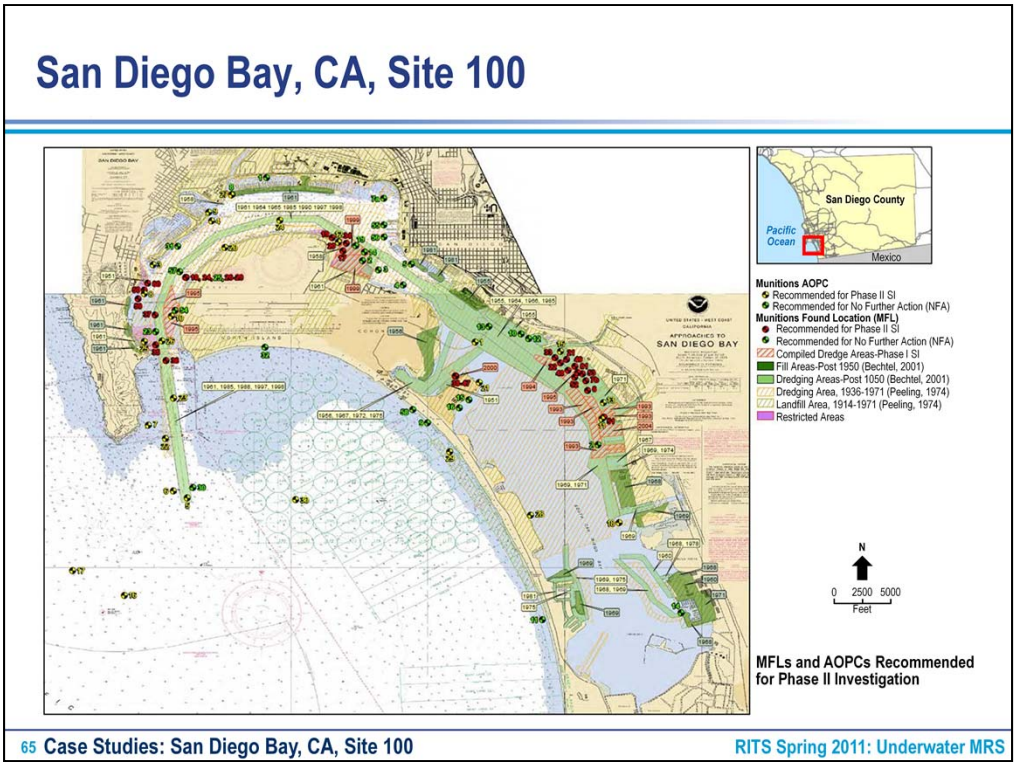
Photo Courtesy of U.S. Navy

63 MC Toxicity and MEC Mobility Model RITS Spring 2011: Underwater MRS

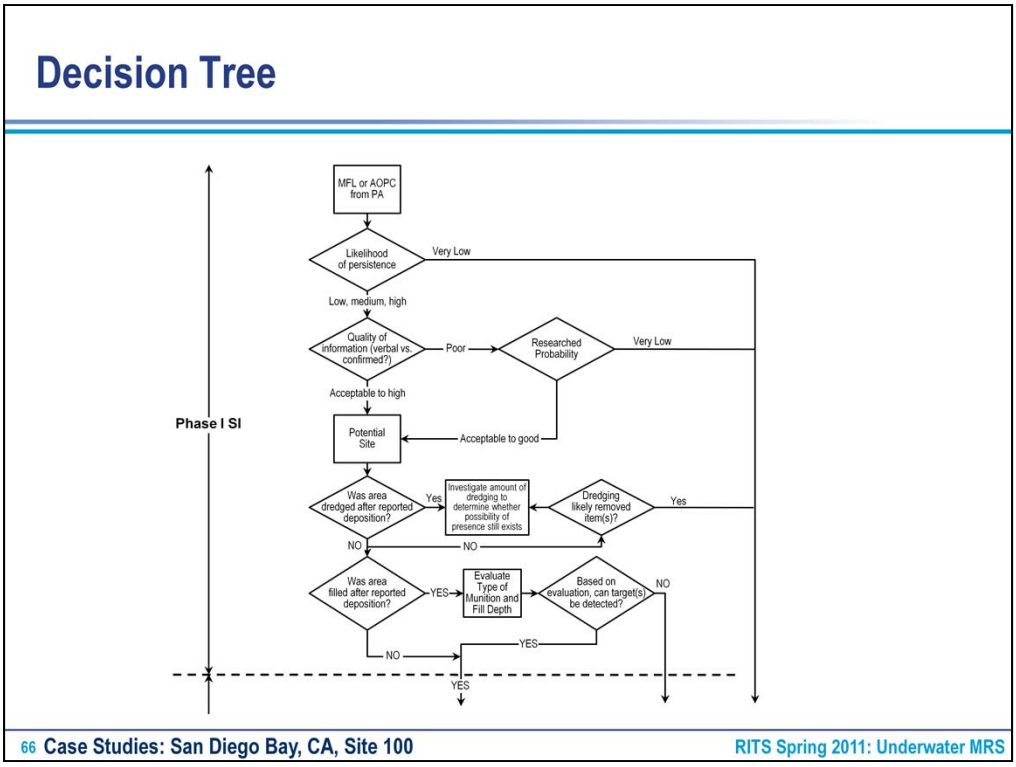
- Natural mitigation is a cleanup option for the munitions which are corroded then get buried.
- This option is used especially in areas where the population rarely visits, AND the coral reef is still growing.

Presentation Overview

- Policy
- Underwater MRS Characteristics and Challenges
- Technologies to Investigate and Remediate a MRS
- Confounding Factors
- ► Case Studies
  - San Diego Bay, CA, Site 100
  - Jackson Park Marine, WA, Operable Unit 3
  - Vieques National Wildlife Refuge, PR
- Summary

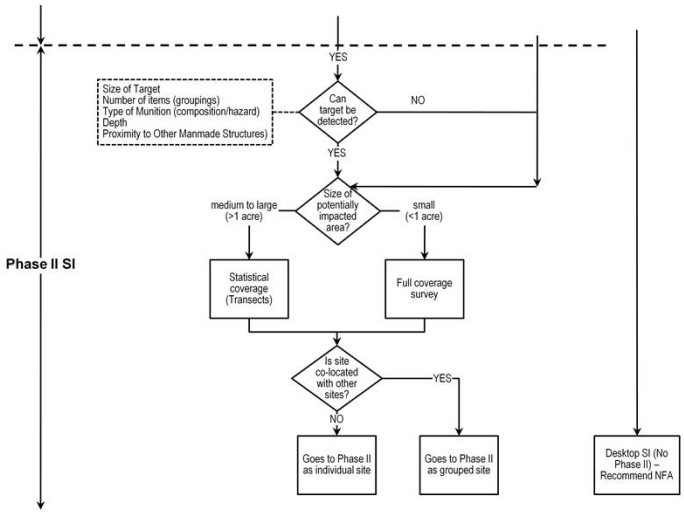


- Case Study San Diego Bay Site 100 which referred to 100 sites within San Diego bay.
- The red and yellow dots on the map are known munitions sites.
- Green areas is where dredging was done in the Bay to keep the Bay functioning as a waterway.
- One reason for these munitions sites is the air base and WWII PBY crashed in the water and lost giant torpedoes that have not been found.



- First, a decision tree was created together with the regulators for San Diego to evaluate each site.
- The details are specific to San Diego.
- The flow chart was key to keeping costs reasonable. The flow chart allowed several sites to be eliminated.
- By including the regulators when the flow chart was generated, all parties were invested in the program and the believed in the approach before starting work at the site.

Decision Tree (cont.)



Phase II Technological Approach

- **Two types of sites**
  - **One acre sites 100% coverage**
  - **Three acre sites statistical coverage (VSP)**
- **Tiered Approach**
  - **Wide area surveys**
    - High resolution side scan sonar
    - Magnetometer array
  - **Spot survey**
    - Ultrasonic imaging sonar and video using ROV

68 Case Studies: San Diego Bay, CA, Site 100 RITS Spring 2011: Underwater MRS

- NO less than 1 acre because with the wing of the equipment. It is difficult to do a small area so small areas were done by 100% coverage.
- The 3 acre sites used visual sampling plan.
- Again, an ESTCP project paid for using the tool (PNNL developed). The tools helps you to set up your own sampling plan. For example if you looked at 75% of an area, you have a 90% confidence that you got all of the munitions in that area using standard to do a statistical analysis. The tool is free and available from PNNL's website.

- A tiered approach was done starting with side-scan sonar to not break expensive equipment in the bay.
- The bed of the San Diego Bay is muddy so stuff is easily buried.
- After side-scan sonar, an EMTA magnetometer was used.
- On target location the ROV would be sent to verify there is nothing on the surface. That's all that was done for the SI.

- The sensor must be able to fly sideways along walls.
- Marine towed array (MTA) was ideal for this, the operator had a joystick and could tilt it.
- The data are processed after because MTA is not a real time process.
- Systems like an underwater pipeline system were selected for further investigation.

Selected Technologies for San Diego (cont.)

- **Sea Botix LBV300-5**
  - **Active heading, pitch, roll, and depth control**
  - **Video Camera**
  - **Lighting system**
  - **Didson 300**
    - 1.8 MHz high definition sonar camera

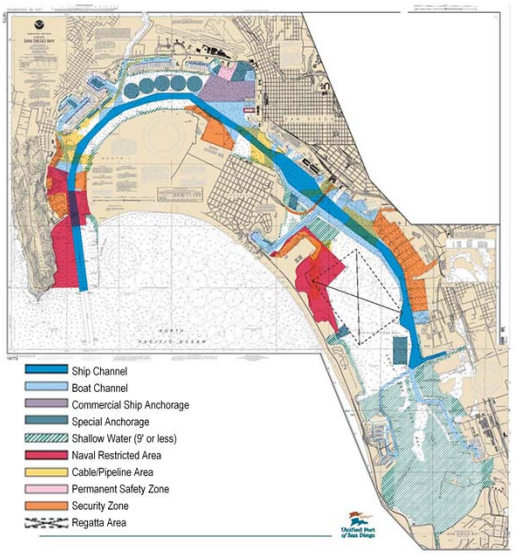
Photos Courtesy of U.S. Navy

71 Case Studies: San Diego Bay, CA, Site 100 RITS Spring 2011: Underwater MRS

Sea Bioticx with sonar camera and movie camera was used to look at spots to look for munitions.

Practical Considerations at San Diego Bay

- Navy Security
- Ship Schedules
- Endangered Species
- Recreation Traffic
- Critical Habitat



72 Case Studies: San Diego Bay, CA, Site 100 RITS Spring 2011: Underwater MRS

- In San Diego Bay, you can only wok in the white area on the map because all of the colored areas have a Navy chief in charge of the security of the area.
- When you tell a Navy chief you want to find UXO in his area then the Navy chief says no, but if you say you want to verify there is no UXO in the area then the reception is better.
- So semantics are important.
- Coordination with Navy Seals can be difficult.
- Also, ship movements are no longer published in advance.
- Choose non-storm season or time when all boats will be gone.
- Remember that after a storm comes, everything can be buried.

Lessons Learned

- **Piecemeal** (I don't think so)
  - Technology smorgasbord
  - Pick the coolest most advanced technologies
- **One stop shopping** (Our clean contractor will handle it)
  - One contractor can not do it all
  - Approach and technology selection and integration is not trivial
- **Every site has unique requirements**
  - "Sure, we've done dozens of UXO sites."

- Lessons learned - Don't do a peace meal.
- There isn't one stop shopping.
- Assemble a team with a technology selection that fits the site.
- All sites are fairly unique. Work with the contractors and do some work yourself.

Lessons Learned (cont.)

- Integrated approach is best
  - Through understanding of the underwater environment
  - Physical limitations of the area
  - Technologies advantages and disadvantages
  - How do the technologies interact together?
  - Unified approach with complementary systems
  - Upfront work (before you touch the water) is the most important phase

- Integrated approach is best and know your environment.
- Know the limitations of the area and understand the technology.
- Up front work is vital before putting a toe in water. In the long term, it can save a lot of money.

Presentation Overview

- Policy
- Underwater MRS Characteristics and Challenges
- Technologies to Investigate and Remediate a MRS
- Confounding Factors
- ► Case Studies
  - San Diego Bay, CA, Site 100
  - Jackson Park Marine, WA, Operable Unit 3
  - Vieques National Wildlife Refuge, PR
- Summary

Conceptual Site Model

- **OU 3 Marine is primarily subtidal areas of Ostrich Bay, WA**
  - **Shallow bay roughly 336 acres with most areas 20 feet deep; maximum depth is approximately 40 feet**
  - **Surrounded by military/non-military residential and non-industrial land use**
  - **Explosive hazard from potential exposure to DMM not UXO**
  - **Source of DMM**
    - Mishandling and loss from operations associated with former NAD Puget Sound
    - Thousands of DMM items found in bay, mainly near piers
  - **Pathway for potential exposure**
    - Contact with sub tidal sediments
  - **Receptor**
    - Limited recreational diving, boat traffic, etc.
    - Potential for future tribal and non-tribal shellfish harvest (Geoduck)
    - No harvesting currently permitted

Geoduck
Photo Courtesy of WDFW

76 **Case Studies: Jackson Park Marine, WA, OU 3** **RITS Spring 2011: Underwater MRS**

- Jackson Park is in Ostrich Bay Washington.
- Piers where loading and off loading of munitions were done but they dropped half of then during loading and unloading.
- The tribes own all the fishing, etc.
- They were to be able to go out a pick up clams so the Navy is under pressure to clean it up.

RI MTA Survey Boundary 2006 and 2009 (approx.)

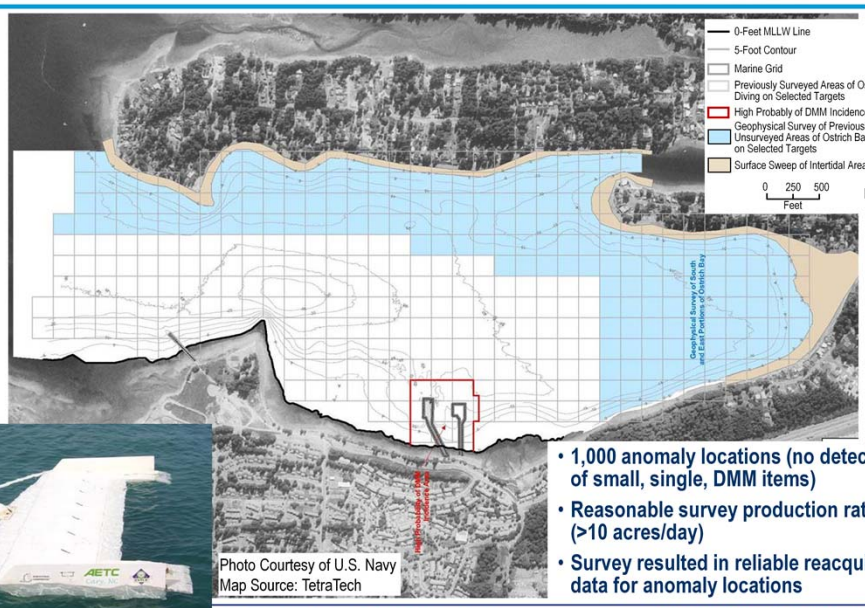


Photo Courtesy of U.S. Navy
Map Source: TetraTech

- 1,000 anomaly locations (no detection of small, single, DMM items)
- Reasonable survey production rates (>10 acres/day)
- Survey resulted in reliable reacquisition data for anomaly locations

Jackson Park Marine, WA, OU 3

RITS Spring 2011: Underwater MRS

Remedial Investigation Results

- Diver anomaly reacquisition & identification
- Contractor divers investigated 822 targets
  - 208 DMM items and 105 MPPEH items removed
  - 6,480 pounds of scrap removed
  - DMM items found in areas removed from Piers

Concretia on DMM items
Photo Courtesy of U.S. Navy

- First thing is take out MTA and survey.
- Then send out divers to investigate each of the anomalies that the MTA picked up.
- Divers were successful.
- Pier and former pier were not surveyed due to size of MTA.
- 208 munitions found and thousands of scrap.

Pier Area Pilot Study

- Pier Area Pilot Study
  - Site of overwhelming majority of sub tidal DMM finds
  - Conceptual Navy/EPA agreement to perform remedial action
  - Pilot study to optimize DMM removal approach
- Technologies and approaches evaluated
  - Standard and modified clam shell dredge bucket
  - Modified skeleton excavator bucket
  - Diver instrument aided search and recovery
  - Bottom Towed EM-61 survey support

Photo Courtesy of Norfolk Dredging Company

79 Case Studies: Jackson Park Marine, WA, OU 3 RITS Spring 2011: Underwater MRS

- Pilot study used clam shell dredge to clean up pilot area but it did not work.
- It all fell through the fingers of clam shell.
- Slow, expensive only mud picked up.

Pilot Study Conclusions

- Dredging and sediment processing should be minimized
  - Low production rates combined with high equipment and labor costs
  - Significant impact to benthic environment and ecosystem
  - Not demonstrated as reliable for DMM recovery
  - Best suited to areas of high metallic clutter and possible DMM incidence

Photo Courtesy of Norfolk Dredging Company

Pilot Study Conclusions (cont.)

- **Bottom drug EM sled and diver survey and clearance**
  - Best process based on seed item recovery (100% in test plot) and viability for most areas
  - Production rate of about ⅛ acre per day per dive team
  - Process costs low compared to dredging/sediment
  - Low impact to benthic receptors and site ecology

Photos Courtesy of U.S. Navy

81 Case Studies: Jackson Park Marine, WA, OU 3 RITS Spring 2011: Underwater MRS

- Other side of pier, bottom drug EM sled and diver were used.
- Worked well and was cheaper than clam shell dredge.
- Dredge had loq=w production rate, suited for stuff where lots of metallic stuff that magnetometer cannot differentiate.

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Vieques Island Live Impact Area

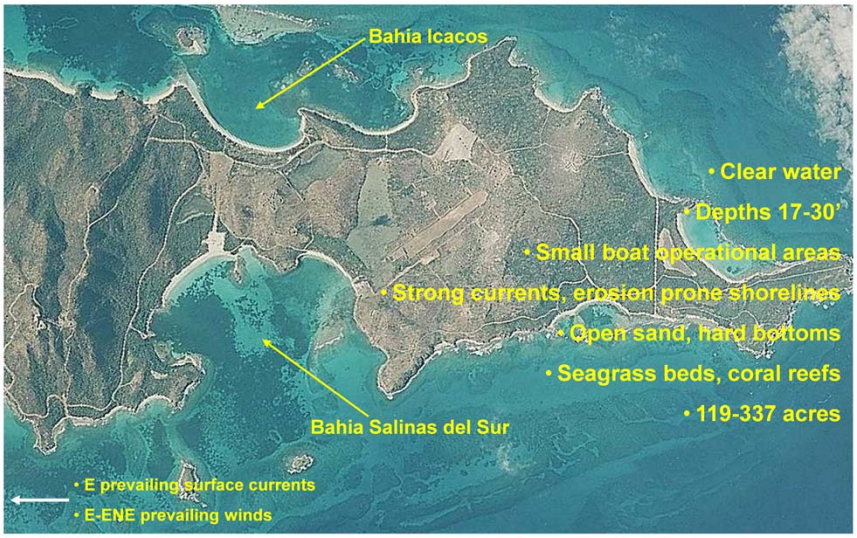


Photo Courtesy of U.S. Navy

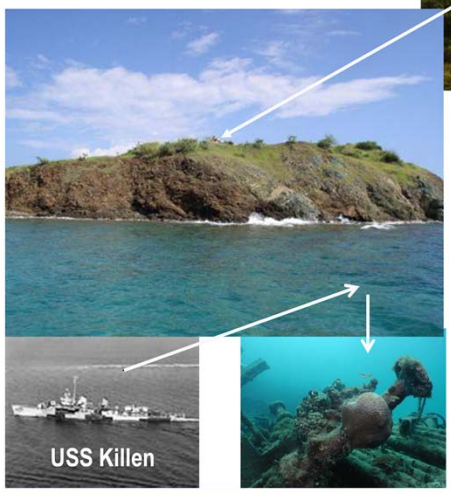
83 Case Studies: Vieques National Wildlife Refuge, PR RITS Spring 2011: Underwater MRS

Conditions impacting Vieques MRP site:

- Meteorological and Oceanographic Conditions – "Hurricane Alley"
  - High Trade winds, rough seas, wave surge, currents, coral reefs, sedimentation
- Remote location of MRP sites
- Maintaining GPS accuracy with base station and mobile GPS
- No marina/port facilities on Vieques Island
- Security for equipment and boats
- Limited local support
- Diver safety, qualifications and execution requirements per EM 385
- Poor vessel and diver support facilities, supplies and logistics
- Expensive and time consuming to ship equipment through Port Customs
- Mob/Demob, daily execution and logistics very time consuming and expensive
- Ongoing terrestrial cleanup operations have priority over underwater investigations
- Data considered only temporary because of UXO mobility, currents and sedimentation
- Groundtruthing mandatory to segregate non-UXO debris, UXOs, and naturally occurring marine growth
- Inability of technology to discriminate between live and inert UXOs
- Mag surveys also detect naturally occurring metals in corals, rocks and sediments
- T&E species and habitat

Land and Sea Based Targets

- Targets for naval ship guns, aerial bombs and artillery



Underwater UXOs from

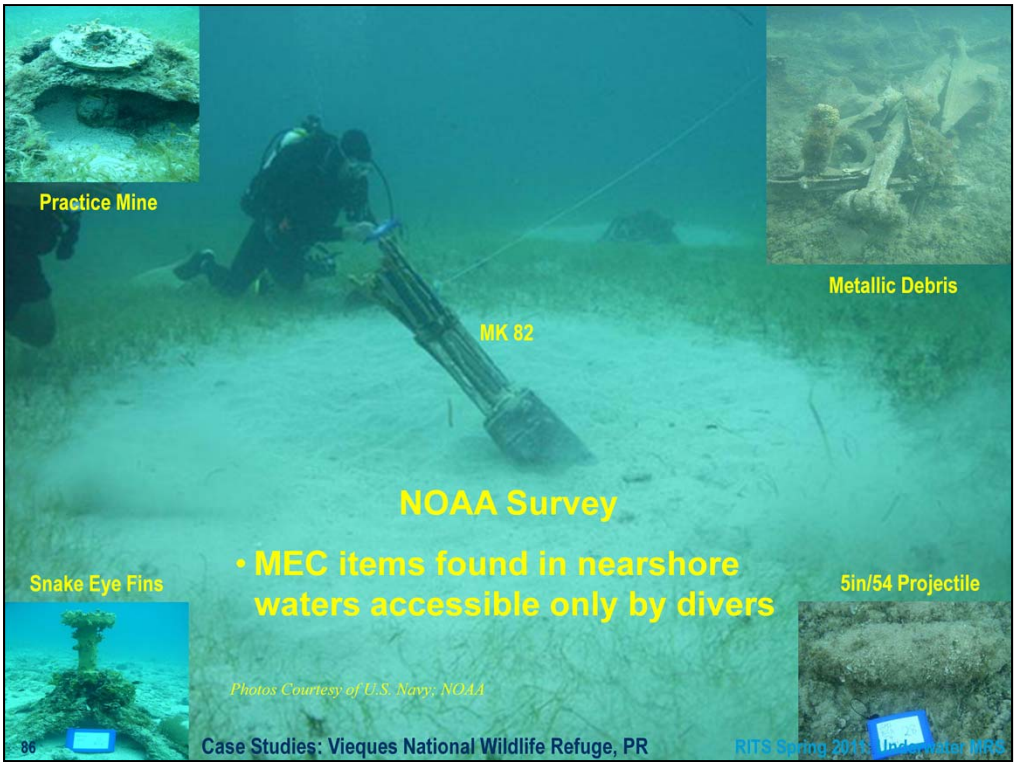
- Ricochet
- Inaccurate targeting
- Target site explosions
- Shoreline erosion

Photos Courtesy of U.S. Navy

Underwater UXO Survey Expertise Provided

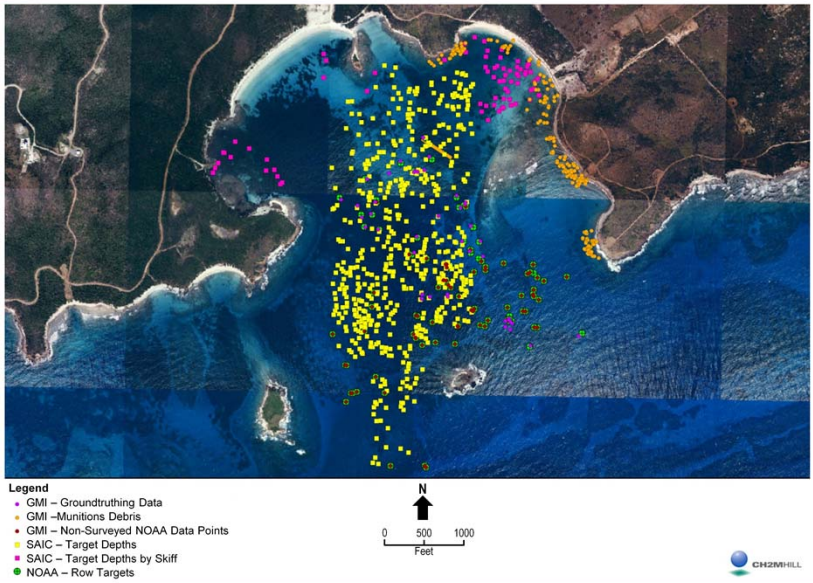
- NOAA
  - Towed side scan sonar
  - Magnetometer
  - AUV (autonomous underwater vehicle
  - ROV (remote operated vehicle)
  - Divers for groundtruthing
- SAIC
  - Towed magnetometer array
- GMI
  - Diver-based UXO mapping

Photos Courtesy of U.S. Navy & NOAA



- EOD divers sweep sites with old school technology – a magnetic detector
- NOAA/GMI divers characterize the data point and site
- Surface items easy to differentiate between UXOs and debris
- Some unidentified surface items completely encapsulated by marine growth
- Some UXOs relatively free of marine growth, unattached to bottom substrates, & could migrate
- Buried items could not be identified
- Buried items under sandy, coral rock sediments and seagrass beds

Combined Demonstration Surveys' Data Points – NOAA, SAIC, and GMI



87 Case Studies: Vieques National Wildlife Refuge, PR RITS Spring 2011: Underwater MRS

- Still working on it after using many different technologies.
- Magnetometers, AUV, ROV and diver based have been used.
- There are a lot of MECs. In map every color is a different project.
- Video-array system used as well. Smaller and may get beat around but gives good info.
- The MTA did well with partially and shallowly buried MECs.
- Pipes and munitions were mixed together so hard to tell what is what.

Demonstration Survey Summaries

- NOAA surveys illustrated the need for a combined technology approach to mapping UW MEC
  - Use sonar, magnetometers, boats, ROVs, AUVs and divers to maximize data
- MTA magnetometer captured proud and buried anomalies
- Site conditions and underwater mobility affect the long term reliability of the data
- Better physical oceanographic and habitat characterization within UW MRS is needed
- UW UXO and MEC debris are becoming incorporated into the habitat structure

Photo Courtesy of U.S. Navy

88 Case Studies: Vieques National Wildlife Refuge, PR RITS Spring 2011: Underwater MRS

Need groundtruthing for all sonar and magnetometer data points.

Presentation Overview

- Policy
- Underwater MRS Characteristics and Challenges
- Technologies to Investigate and Remediate a MRS
- Munitions Constituent (MC) Toxicity and Munitions of Explosive Concern (MEC) Mobility Model
- Case Studies
- ► Summary

Take-Home Points

- Underwater MRSs require a combination of technologies
- Existing technologies are insufficient in discriminating UXO from DMM and inert munitions
- Site oceanographic conditions impact investigation and remediation
- Underwater mobility can be influenced by currents, waves, storms, and prop wash
- Underwater mobility and sedimentation can impact previous surveys' data points

90 Summary RITS Spring 2011: Underwater MRS

- Need a combination of technologies. There isn't a magic bullet.
- An integrated approach is required.
- The hardest thing is to differentiate UXO from junk. There are 100 times more pieces of junk that UXO and it is expensive to pick up a watch piece.
- R&D is still ongoing for differentiating between junk and UXO.
- Underwater movement is a problem.
- Environmental regulations must be included in your investigation and remediation. There may be resistance from regulation.
- Mitigation and removal technology is not well developed.

Take-Home Points (cont.)

- Environmental regulations must be integrated into investigation and remediation
  - Removal actions carry significant environmental regulatory burdens
- MC contaminant ecological risk is very low while MEC explosive safety risk remains high
- Removal mitigation technologies are limited
- Pay close attention to European progress in underwater munitions actions

Take-Home Points (cont.)

- Integrated approach is best
  - Through understanding of the underwater environment
  - Physical limitations of the area
  - Technologies advantages and disadvantages
  - How do the technologies interact together?
  - Unified approach with complementary systems
  - Upfront work (before you touch the water) is the most important phase

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