Kaho'olawe Island Conveyance Commission

Consultant Report No. 22

Unexploded Ordnance in Waters Surrounding Kaho'olawe

Historical Use

Estimates of Ordnance and Hazardous Materials

Technology Assessment for Clearance & Disposal and Clearance Planning

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Final Report to Kaho'olawe Island Conveyance Commission

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ABSTRACT

Most previous research and surveys of unexploded ordnance (UXO) on Kaho'olawe Island have been concerned with the land surface. This report describes research and survey data for underwater UXO in the nearshore waters of Kaho'olawe. Estimates of UXO are calculated from sample survey data.

The report describes unique aspects of underwater UXO detection and prosecution, and assesses conventional and developing technologies for possible use in the nearshore waters of Kaho'olawe. SEATECH Contracting Inc. suggests a combined technology strategy to include the use of humans, marine mammals, video, and magnetometer systems as a means to locate UXO. Conventional prosecution of underwater UXO by "blowing in place" should be replaced by identification and remote recovery whenever possible to protect both environmental and archaeological features of the marine setting. The total area of the nearshore waters out to 120 feet deep is 7259 acres. Clearance of all surface and buried (18" deep) UXO in the entire area, and clearance of selected mooring and infrastructure areas to 6 feet below the seafloor will take 10.0 years and cost $185,864,870. Seafloor surface clearance of the entire area, selective clearance of buried (18" deep) UXO in 44.8% of the entire area, and clearance of selected mooring and infrastructure areas to 6 feet below the seafloor will take 6.0 years and cost $102,491,181. Costs for both plans include long-term follow up activities through 10 years.

ACKNOWLEDGEMENTS

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Survey Team Members

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Norman Chun
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EXECUTIVE SUMMARY

In May, 1993, the Kaho'olawe Island Conveyance Commission (KICC) contracted SEATECH Contracting Inc. (SCI) to conduct a survey of unexploded ordnance (UXO) in the nearshore waters of Kaho'olawe Island, to the 120 foot depth contour. The survey includes a literature search, oral history research, a sample survey in the field, statistical analysis, estimates of ordnance, and a clearance plan.

The goal of the clearance activities in the waters surrounding Kaho'olawe Island is to make this area reasonably safe for human use, while maintaining a healthy marine environment and culturally important archaeological sites.

The coastline of Kaho'olawe is varied, ranging from steep basalt cliffs to sandy beaches. Bottom types include sand, silt, basalt benches, limestone ridges, large boulders, rubble, and coral reef. Precise data on the percentages of each of these bottom types is not available. SCI made rough estimates of the types of sea bottom for the purpose of estimating project costs.

Our survey used the same eight geographical regions as the 1992 Department of Land and Natural Resources, Division of Aquatic Resource (DLNR/DAR) Kaho'olawe Island Nearshore Marine Resource Inventory. The regions are: West (Lae o Kealaikahiki to Honokoa Bay), Northwest (Lae o Honokoa to Kaukamoku), North (Kaukamoku to Lae o Kukui), Northeast (Lae o Kukui to Lae o ka Ule), East (Lae o ka Ule to Lae o Halona or Kanapou Bay), Southeast (Lae o Halona to Lae o Kuakaiwa), South (Lae o Kuakaiwa to Wiliwilipeapea), and Southwest (Waikahalulu Bay to Lae o Kealaikahiki).

ESTIMATE OF UXO IN WATERS TO 120 FEET

The types of UXO found in the water are the same as those found on land. The majority of the UXO in the water are the ones that missed the targets on land, although erosion on land has transported some ordnance pieces, such as spent rocket casings, down the runoff canyons from land into the water. There are some items only found in the water, such as practice mines and torpedoes.

A number of limited surveys have been conducted in Kaho'olawe waters which have observed and documented the presence of UXO. No complete underwater survey of Kaho'olawe has ever been conducted for all waters to the 120 foot depth. The most extensive UXO surveys were those conducted in 1976 and 1978.

Survey Methods

We employed four principal search methods: towed divers, free swimming divers, towed video and a magnetometer. In shallow waters, skin divers were towed to visually search the bottom for exposed UXO and hazardous materials over a 30' wide search swath. In deeper waters or whenever visibility was too poor, SCUBA divers were used. Free swimming divers were also used to thoroughly search smaller selected areas to qualify the towed diver search method. The towed video camera system and a magnetometer were primarily employed to test their effectiveness as a detection option in the Kaho'olawe setting.

Survey Results

The SCI survey found ordnance in most areas reported in previous underwater surveys. We also found other areas of high UXO contamination previously unreported, such as Makaalae and near Papakaiki. In the case of the Puu Koae area, no UXO was found, contrary to our expectations based on the history of military use. We found a total of 76 exposed UXO items in waters to a depth of 120'. We searched a total 843 acres which represents 11.6 percent of the total 7,259 acres. The majority of the area searched was in shallow waters, the area assumed to have the most UXO.

Analysis of Survey Data

The observers could only count the exposed UXO on the hard surfaces (rock, coral, and some heavy rubble surfaces) and not under the compliant surfaces (sand, silt, mud, and light rubble) and slide zones. Data in these sites could only be extrapolated when data were available from the hard surfaces.

Two studies were made to extrapolate the collected data into the entire surrounding waters. The first was to establish extrapolation to correct for observer error, and then to extrapolate to correct for hidden UXO. This was done under the assumption of a complete sampling technique and results. The second study was a short statistical study to find a multiplicative factor to account for incomplete sampling. We then multiplied the factor from the second study against the results of the first study. This yielded an upper estimate based on any chosen confidence factor for the count of UXO. The data are presented in Appendix B in a form that can be used for future studies. The studies were done region by region. This was done so that more accurate knowledge might be gained for each region since they were assumed to differ just as areas on the land masses differ in UXO counts.

In the east, north, and northwest regions we should expect a total of 161, 325 and 623 UXO respectively. This is a total of 1109 UXO with no estimate of the confidence level.

In the southwest, south, and west regions we should expect a total of 498, 39, and 277 UXO respectively. This is a total of 814 UXO with no estimate of confidence level. We expect these numbers to be more accurate because of the larger area searched.

In the southeast region we have no data; nothing can be said definitively about this region. Any estimate made by interpolating or extrapolating data from adjoining regions is of questionable value. The adjoining regions have their own characteristics.

In the northeast region we found no UXO but only sampled 2% of the region; nothing can be said with any accuracy. Any estimate made by interpolating or extrapolating data from adjoining regions is of questionable value. The adjoining regions have their own characteristics.

POSSIBLE DETECTION AND REMEDIATION TECHNOLOGIES

For all detection and remediation activities, it will be important to have extremely accurate (to within 1 meter) navigation systems, and voice/data communications systems. The most cost-effective approach would be for land-side and ocean clearance activities to share the major navigation and communication systems. In addition, ocean clearance activities have special requirements for underwater and towed instrument navigation, which must be integrated with the main navigation system. Data can be organized by a Geographical Information System (GIS), which allows detection and remediation activities to record, report, and analyze data using overlapping maps.

Detection

A strategy for detecting UXO in the underwater environment must consider the strengths and limitations of natural sensory systems and man-made technologies that use acoustic, electric, magnetic, or electromagnetic fields. There are many different possible shapes and sizes of objects to be detected, in many different bottom types, depths, water clarity, and sea conditions. Some UXO is buried, and cannot be seen at all. Some has been colonized by coral and other organisms, its shape and color camouflaged beyond recognition. Each of the detection techniques discussed here may be useful in appropriate conditions.

After analyzing the advantages and disadvantages of the technologies summarized below, SCI has developed the following proposed detection scenario:

1) A magnetometer survey will first be conducted using a proton precession magnetometer towed in a vehicle with precise depth control and a precision

navigation system to provide accurate locations. This survey will provide locations of all concentrations of ferrous metal, buried and exposed, around the island.

2) The final detection effort will be conducted in conjunction with remediation for successive clearance areas progressing around the island.

3) Final detection will be accomplished using a combination of underwater video, divers and marine mammals.

Towed Divers and Swimmers

No current technology can match the human eye and brain in recognizing a variety of shapes in a field of clutter. An experienced human swimmer or diver can see proud (unburied) ordnance and discriminate it from the surrounding rock, coral, and rubble. Sometimes shape is the only useful cue, since the natural camouflaging process has usually matched the color of the surroundings.

Towed Video Camera

A video camera, towed from a boat, is an excellent alternative to divers in deeper waters where there is less clutter, less UXO covered by shifting substrate movements, and less marine growth. The use of video is a kind of 'telepresence', allowing the human observer to view the bottom as if he were actually there, while physically remaining at the surface, conserving bottom-time. The task of visually recognizing ordnance is more difficult using video, compared to viewing directly. While conventional single-camera underwater video systems can be used to identify UXO in perfect conditions, it is much more difficult under poor visibility and where the UXO may be nestled in a surrounding substrate of coral or rubble. New developments in economical stereoscopic displays make it practical for a towed video system to use stereo.

Scanned Laser Imaging Systems

Scanned laser systems are similar in purpose to a video camera system. The scanned laser system, or flying spot scanner, can be thought of as a backwards video camera. The advantage of the scanned laser system over a video camera system is that theoretically, performance in turbid water can be improved. In turbid water, the particles in the water scatter light, which reduces contrast in the image. By reducing the amount of water volume shared between light and camera, or between photodetector and scanning laser, the backscatter can be reduced. This is more important in deep water, where artificial illumination is required.

Sidescan Sonar

Sidescan sonar uses a towed sonar transducer with a directional shaped sound beam. The beam is a line shape (wide vertically and narrow horizontally) that scans along the track of the towed 'fish' to build up a picture of the bottom. Usually two-sided units are used to build a picture of both sides of the track.

Sidescan pictures are very limited in what they portray of the actual objects on the bottom. Light and dark areas of the image represent areas of high and low acoustic reflectivity which can be severely confounded by irregular shapes, surfaces, and material composition of the actual objects being viewed. High-frequency sidescan sonar may be useful for searching areas of poor water clarity, with a relatively shallow slope and minimum clutter from coral, rubble, and rocks. Exposed UXO on smooth sand, mud, or silt bottoms may be recognizable on the display.

Magnetometer

In many offshore areas of Kaho'olawe, items of UXO are buried under sand, silt, coral, or rubble. Magnetometers are the most widely used method of searching for underwater buried UXO. Any ferromagnetic material will cause a local distortion in Earth's magnetic field. The magnetometer senses these variations which produce an 'anomaly' in the recording of the magnetic field strength. Multiple passes over the same search grid, at precisely controlled altitudes above the sea floor, are required to provide the best possible magnetometer data. The data from the multiple passes can be processed and combined to create a field strength map which can provide information on the location, size, shape and orietnation of buried objects.

Dolphin Object Location and Marking System

Dolphins use biosonar as one of their primary senses. They have evolved highly sophisticated biosonar which allows precise identification of objects and even determination of interior details of objects which are visually opaque. The dolphins produce clicks and process echoes over a wide range of frequencies, from the low attenuation long wavelengths to the high resolution short wavelengths. Their capability to quickly find and identify buried objects exceeds man-made systems in certain conditions. Trained dolphins, working with the US Navy, find objects in murky water, diving easily to depths that would limit bottom-time for human divers.

The Navy has been conducting marine mammal research and deploying marine mammal systems on various missions since the 1960's. The dolphin systems have a proven track record at locating a variety of instrument packages. It has only been recently, with the end of the Cold War, that much of this information has been declassified and released. A Cooperative Research and Development Agreement, or CRADA, is a program to help explore new partnerships of private industry with military agencies. The CRADA sets out a mutually beneficial relationship between the government agency and the private-industry contractor so that they can work together on leading-edge research tasks. SCI proposes that a CRADA provides a mechanism which would allow the Navy's marine mammals to be used in the location of UXO around Kahoolawe.

Remediation

Environmental conditions will play a major role in determining remediation methods. Sea state, water depth, underwater visibility, current, wind speed, bottom composition, bottom profile, and the extent to which UXO might be "grown" into the bottom are some of the factors that will influence the decision process. One single method will not work for all conditions. A variety of approved methods must be available to the clearance team, which will then adopt the remediation program appropriate to the existing environmental conditions. The following are the possible remediation techniques which may be considered for clearance of Kaho'olawe Island:

Remove
Encapsulate and Remove
Encapsulate and Leave
No action
Blow in Place (BIP)

The choice of remediation techniques will be based on two assumptions. The first assumption is that safety to humans (clearance personnel and end users) is the primary concern. The second assumption is that whenever possible, UXO disposal by blowing in place should be avoided. The process of establishing priorities for the remediation techniques must involve input from experts in the field of UXO disposal, discussions with Government agencies responsible for regulating environmental issues, members of the Protect Kaho'olawe Ohana (PKO), members of the Kaho'olawe Island Conveyance Commission, academic research institutions, and other concerned citizens.

Removal or "Pick Up and Carry Away"

Removal of the ordnance is a common practice in UXO remediation projects on land. The EOD term for removal is "Pick Up and Carry Away" or PUCA. UXO should be removed from the shallow waters surrounding Kaho'olawe whenever removal can be accomplished safely. However, it is important to note at this point that while removal techniques are tried and tested on land, many known and some unknown conditions might exist underwater that would preclude removal as a viable option.

We conducted interviews with 12 experts in the field of UXO disposal. All of the interviewees stated that removal should not be considered a safe option for underwater UXO disposal if it requires human contact with the UXO. On land, UXO can be carefully examined to determine a relative degree of safety. In many cases of underwater UXO, the appearance of the UXO has been altered to the point where adequate inspection is not possible or environmental conditions are such that movement of the UXO would be unsafe. Every phase of removal (lifting, transporting, dumping, etc.) increases the chances of detonation making inadvertent detonation a very real possibility.

There may, however, be situations in which removal of UXO by remote methods can be safely and practically accomplished. In our opinion "remote operation" implies that humans are kept at a safe distance during the operation. The distance required for safety depends for the most part on the size of the UXO and the water depth. If underwater UXO can be adequately inspected and judged safe to move by a qualified EOD technician, then removal might be the choice for remediation. The ultimate determination of safety must be left with the disposal team.

Remotely Operated Vehicles (ROV) are commonly used to perform work underwater. However, the effectiveness of ROV's to locate and remove UXO from the waters surrounding Kaho'olawe will be limited by a variety of environmental and operational factors, such as: frequent rough sea conditions, strong nearshore currents, silatation in some areas, and the potential high cost of equipment replacement in the event of accidental detonations.

To summarize our opinion of removal as a method of remediation, remote systems should be employed whenever practical. Divers should only be involved with removal operations if there is absolute assurance that the UXO is safe to move.

Encapsulate and Remove & Encapsulate and Leave

There may be situations that make removal desirable but unsafe unless the UXO is first encapsulated in concrete. We place this method second on the removal prioritization because it still accomplishes the goal of removal without detonation in place and in our opinion adds a margin of safety to the removal operation.

If the encapsulated UXO cannot be removed, the next best option in the order of priority, is to leave the encapsulated UXO in place. Encapsulation, to a certain degree, denies access to the UXO. However, encapsulation will not render the UXO safe. Unless removed, it will remain a hazard, and will possibly hamper future UXO monitoring surveys.

If done properly, encapsulating UXO in concrete might make it less of an environmental hazard. If this were found to be the case, ocean dumping of the encapsulated UXO might be a viable consideration in the permit process.
No Action

There may be times when leaving UXO in place will be the safest and most environmentally sound approach. While leaving it in place can't be considered remediation, it may be desirable for critically important cultural or environmental reasons.

Blow in Place

Blowing in place (BIP) should only be used if, in the opinion of all concerned, no other option is feasible. However, situations will likely occur in which BIP is the only safe method of disposal. It is important to reemphasize at this point that all of the U.S. Navy EOD Technicians interviewed stated that removal should not be considered a safe option for underwater UXO disposal if it requires human contact with the UXO. BIP is the method of choice of the U.S. Navy.

Should the decision be made to BIP, there are several factors to consider. One consideration is how much High Explosive (HE) will be required to achieve total destruction of the UXO. The amount of HE must not be so great as to cause unwarranted and excessive damage to the surrounding underwater flora and fauna. We recommend utilizing an electric firing train over nonelectric initiation. Electric firing offers the EOD team almost total control over the moment of detonation which enhances the safety of the team. The primary concern with BIP is the potential for environmental damage and destruction of archeological features. A well designed remediation decision-making protocol that insures input from all concerned parties needs to be in place to minimize the potential damage from BIP.

POTENTIAL PLAN FOR CLEARANCE

In order to produce a plan which allows a preliminary cost estimate and schedule to be developed assumptions must be made about several variables which impact the planning process. These assumptions include: the future intended use of the island waters; the technologies selected for detection and remediation; and the risk assessment criteria. In addition, clearance categories need to be established in order to effectively estimate the amount of work which will be required to complete the task. We suggest three categories of clearance for the waters around Kaho'olawe to a depth of 120 feet.

Category 1 - clear exposed UXO from the sea floor.

Category 2 - clear UXO to 18 inches below the sea floor.

Category 3 - clear UXO (in certain anchorages) to 6 feet below the sea floor.

To the best of our knowledge, no decision has been made about which government agency will administer the job of underwater UXO remediation. In the past, UXO remediation jobs have been administered by the U.S. Army Corps of Engineers, and we assume that will be the case. Contractors will be required to work closely with the Army Corps of Engineers on project coordination including: quality assurance programs, operations planning and procedures, permits, and staff training programs.

We offer two clearance options for consideration:

Option A

1. Clearance of all exposed UXO from the waters surrounding Kaho'olawe from shore out to 120 feet deep.

2. Clearance of all buried (18" deep) UXO from the waters surrounding Kaho'olawe from shore out to 120 feet deep.

3. Clearance of all buried (6' deep) UXO from shore out to 120 feet deep in designated deep draft anchorages (Cat 3 Heavy Mooring Areas, Hana Kanaia, Kuheia, and Hakioawa).

Option B

1. Clearance of all exposed UXO from the waters surrounding Kaho'olawe from shore out to 120 feet deep.

2. Clearance of all buried (18" deep) UXO from shore out to 120 feet deep in Special Development Areas (SDA's: Hana Kanaia, Honokoa, Ahupu, Kuheia, Kaulana, Hakioawa, Kanapou, Kamahio) Note: the Kuheia SDA has been extended to the bay to the south which is a good anchorage during prevailing winds.

3. Clearance of all buried (6' deep) UXO from shore out to 120 feet deep in designated deep draft anchorages (Cat 3 Heavy Mooring Areas, Hana Kanaia, Kuheia, and Hakioawa).

In all probability, the clearance of UXO from the land portions of Kaho'olawe will require substantial upgrading of the existing infrastructure. For cost estimating purposes, we have structured the underwater clearance operation to be autonomous and independent of the land clearance operation. However, these groups should share resources and infrastructure including: communication and navigation systems, maintenance, housing, food, medical, transportation, and others. The underwater and marine mammal operations will require some dedicated facilities.

Some of the first items of infrastructure that might be installed on the Kaho'olawe work site are the first elements of a Mooring Buoy Anchorage System. A mooring buoy system has a number of advantages over anchoring by conventional means. The foremost is eliminating the potential of dragging anchors striking UXO. It also provides good moorings for a greater number of boats in a limited area, and it minimizes environmental damage caused by conventional anchoring. Such a system has potential long term benefit for the the proposed Kaho'olawe Island Reserve Commission (KIRC), in that it will provide a means to control access to Kaho'olawe waters by requiring special permission to moor boats on the mooring system. The reservation process can be adjusted according to the KIRC's need to address cultural or environmental concerns. The initial areas cleared are those needed to support clearance operations. Next are areas of projected heavy use. Finally, general clearance of island waters will be conducted.

The objective of the remediation program will be to make the waters surrounding Kaho'olawe reasonably safe for human use, while minimizing environmental damage. If the disposal team determines that a particular piece of UXO must be blown in place or left alone, then we recommend that steps be taken to involve concerned parties in the decision. This can be done through establishment of an Oversight Commission which would notify the appropriate concerned parties (NMFS, DLNR/DAR, PKO, etc.). The concerned parties would have two weeks to give input to the Oversight Commission. The Oversight Commission would then give direction on what action should be taken.

UXO may be exposed during large storms or washed into the ocean from land for many years in the future. We suggest development of a plan for annual areal surveys that would completely canvas the waters to 120 feet every ten years.

Cost estimates have been developed for both Clearance Option A and Clearance Option B. Estimated clearance rates for all clearance categories for Option A and Option B resulted in project durations of 10.0 years and 6.0 years respectively. These rates take into account lost operational time due to weather, daily pre-clearance and post-clearance activities, clearance related support activities and unexpected interruptions. Both plans include provision for long-term follow up through 10 years.

The proposed underwater UXO clearance team totals 71 individuals. We used the current prevailing wage from the State of Hawaii Department of Labor and

Industrial Relations Wage Rate Bulletin. The same staffing model was used for both estimates, because the duration of clearance activities was changed to account for the different levels of activity.

The gross hourly wage for the 71 person team is calculated to be $2072. We added a 5% inflation multiplier, assuming that hourly wage rates will increase by this amount by the time the project actually begins operations. When an industry average burden of 2.5 times the gross hourly wage rate is added, a fully burdened hourly wage rate of $5,439 is obtained. The annual labor cost was then obtained by multiplying the fully burdened hourly wage rate by 2080 working hours per year. This yielded a annual labor cost of $11,313,939 for the first year of operation.

Estimates of the total project cost for both Option A and Option B assume 5% annual increases in labor costs. Annual operating costs are estimated at 17.5% of annual labor costs and include vessel charters and associated expenses, transportation, equipment repairs, service, and replacement, procurement of specialized equipment, supplies, and utilities. Mobilization costs of $1,500,000 include project and operations planning, marine mammal mobilization, communications and navigation systems development. Demobilization costs are for clean-up of the job site after the project is complete. Long term follow-up is an allocation for annual surveys to check for newly uncovered UXO. A 10% contingency provision is made on top of the overall annual cost. The total cost of Option A clearance is $185,864,870. The total cost of Option B clearance at 10 years is $102,491,181.

1.0 INTRODUCTION

1.1 Overview

In May, 1993, the Kaho'olawe Island Conveyance Commission (KICC) contracted SEATECH Contracting Inc. (SCI) to conduct a survey of unexploded ordnance (UXO) in the nearshore waters of Kaho'olawe Island, to the 120 foot depth contour. The contract scope of work includes a literature search, oral history research, a sample survey in the field, statistical analysis, estimates of UXO, and a clearance plan.

The goal of the clearance activities in the waters surrounding Kaho'olawe Island is to make this area safe for human use, while maintaining a healthy marine environment and culturally important archaeological sites. Intended uses for the area have been described in the KICC Final Report [1] and in Act 340 of the 1993 Hawaii State Legislature [2]. This Act establishes a "Kaho'olawe Island Reserve" and "The Kaho'olawe Island Reserve Commission" (KIRC) to manage the island when it is turned over to the State of Hawaii.

The Protect Kaho'olawe Ohana (PKO) will play a continuing stewardship role in the future of Kaho'olawe. The Ohana is presently conducting research regarding traditional fishing techniques, offshore archaeological sites, and future types of use of Kaho'olawe waters. The PKO research results should be considered during planning of the final underwater clearance.

1.2 Nearshore Environment

The coastline of Kaho'olawe is varied, ranging from steep basalt cliffs to sandy beaches. Bottom types include sand, silt, basalt benches, limestone ridges, large boulders, rubble, and coral reef. Precise data on the percentages of each of these bottom types is not available. SCI made rough estimates of the types of sea bottom for the purpose of estimating project costs.

Our survey used the same eight geographical regions as the 1992 Department of Land and Natural Resources (DLNR) Kaho'olawe Island Nearshore Marine Resource Inventory [3]. The regions are: west (Lae o Kealaikahiki to Honokoa Bay), northwest (Lae o Honokoa to Kauka moku), north (Kauka moku to Lae o Kukui), northeast (Lae o Kukui to Lae o ka Ule), east (Lae o ka Ule to Lae o Halona), southeast (Lae o Halona to Lae o Kuakaiwa), south (Lae o Kuakaiwa to Wiliwilipeapea), and southwest (Wai Kahalulu to Lae o Kealaikahiki). These regions are detailed in the Maps Section at the end of this document.

Possible underwater archaeological and historical sites are described in "Na Wahi Pana o Kaho'olawe" [4] and the KICC 1993 report to Congress [1]. In addition, Ross Cordy of DLNR, Historic Preservation Divsion [5] has suggested that canoe launch and landing channels may contain artifacts, such as adzes from the Puu Moiwi quarry. Fishing grounds may have octopus sinkers, fish hooks, and anchor stones for kaka line fishing.

Fishing grounds include:
- Laeokuikui, a long-line fishing area off Lae o Kuikui
- Laepaki (Lae Kealaikahiki), a deep sea fishing ground five miles out that reportedly rises to 15-20 fathoms deep, used for long-line (kukaula) fishing
- Honokoa, off Honokoa Bay, a kukaula area
- Ahupunui, off Ahupunui Bay, a kukaula area
- Lua ka Ulua, near Kuheia
- Na Koa Lua, off Kanapou

Possible canoe launch and landing sites include:
- Kanapou
- Ahupu Bay

Significant shipwreck sites near Kaho'olawe include:
- Olga, a four-masted schooner wrecked in May 1906 on the northern point of Hakiowa Bay
- Lark, came ashore in March, 1813 at Papakaiki
- Keola, 1840

Other interesting sites are:
- Kalua o Kamohoalii, possibly a sea cave near the northern end of Kanapou Bay, home of the shark-king Kamohoali'i.
- Kamohia Shrine, another sea cave reached by swimming.

2.0 MILITARY USE OF KAHO'OLAWE WATERS

Military use of Kaho'olawe Island has been summarized in the KICC 1993 report to Congress, "Kaho'olawe Island: Restoring a Cultural Treasure" [1] and in the Office of State Planning 1992 report "Explosive Hazards Associated with the Waters Surrounding Kaho'olawe Island" [6]. More information on military use was obtained from participants in the oral history research described in Section 3.

2.1 Types of UXO in the Water

The same types of UXO that are found on the island of Kaho'olawe are found in the waters surrounding the island. Types of UXO that are only found in the water include practice mines and torpedoes. Projectiles that fell short of nearshore targets make up the majority of underwater UXO. In some cases, erosion may have transported UXO from the island into the waters surrounding the island. A summary of possible UXO types includes [6].

- General purpose bombs - 100 lb, 250 lb, 500 lb with TNT loads
- Demolition bombs - 1000 lb with cast TNT loads
- Armor-piercing bombs up to 500 lb with cast TNT loads
- Explosive rockets 2.75 inch-11.75 inch with TNT loads
- Artillery projectiles 20mm-16 inch
- Torpedoes 10-21 inch diameter, 6-24 feet long with explosive loads of TNT, HBX, RDX, or Torpex.

Additionally, there may be practice bombs (still dangerous, since they contain a shot-gun-shell-sized charge), and practice mines (which may contain flares). Since Kaho'olawe was never actually a war zone, some UXO types, such as live mines, are not likely to be present.

2.2 The Presence of UXO in the Nearshore Environment

The presence of UXO in the waters surrounding Kaho'olawe creates unique problems for the process of conveying the island from the United States to the State of Hawaii. Prior to opening the island for civilian use, the State of Hawaii must insure that the waters are made reasonably safe for human use. While range clearance and UXO remediation are becoming more and more common practice, there is very little recorded history of underwater remediation. The U.S. Navy Explosive Ordnance Disposal Technicians are considered to be the leading authorities on clearance of underwater UXO. EOD Mobile Unit One has completed numerous underwater clearance operations within the State of Hawaii. For U.S. Navy EOD, the method of choice for disposing of underwater UXO is Blow in Place (BIP).

While BIP is a proven method and may well be the method of choice for eventual clearance, it is incumbent upon parties involved with the clearance planning and operations to investigate alternate methods. Environmental considerations for the clearance operation will be significant, as will human safety considerations.

The goal of the clearance operation must be to carry out a plan that is production oriented and sensitive to environmental issues, but most importantly, absolutely bound by strict human safety standards.

2.2.1 Human Risks

There is no way to quantify the risk to people using the waters surrounding Kaho'olawe. We are not aware of any recorded accidents involving underwater UXO at Kaho'olawe. But, we make the assumption that UXO in the waters that are used by humans creates a hazard. As long as UXO remains in the waters, there is a chance of detonation. There is a human risk from UXO to the users of Kaho'olawe waters and to the workers who will be involved in the clearance operations.

The UXO poses major potential risks to two human activities. First, there is great risk to any vessel attempting to anchor in waters littered with UXO. The second risk major risk category is that to divers who, knowingly or unknowingly, attempt to tamper with or remove the UXO objects.

2.2.2 Environmental Risks

Environmental risk results from the long term decomposition of the UXO casings, the erosion of the explosive material inside, and the damage to the localized area should UXO detonate. Clearance plans that call for Blowing In Place (BIP) must fully evaluate the environmental impact of detonation. Environmental considerations include: damage to marine mammals (whales, dolphins, Hawaiian Monk Seal, etc.); damage to sea turtles; damage to large fish and eels (sharks, rays, Ulua, morays, etc.), smaller fish, corals, and other invertebrates. Though precise data are lacking, experts agree that it will take up to 50 years for a coral reef to regenerate to its pristine state - and the resulting craters will be permanent.

2.2.3 Differences in UXO Present Underwater

For the most part, UXO found on land at Kaho'olawe can be expected to be found in the waters surrounding Kaho'olawe. One noteworthy exception is the presence of submarine launched torpedoes, which have been found in Kamohio Bay and Kanapou Bay.

The general appearance of underwater UXO can be substantially altered by the environment. On impact with the water, tail fins are sheared off. In areas of coral, the UXO might become consolidated into the coral formation. In rocky areas, marine growth can cause UXO to blend in with the surrounding environment. The altered appearance makes positive identification difficult and determination of the degree of safety of the UXO virtually impossible. Therefore, every piece of underwater UXO must be treated as an extremely dangerous object.

3.0 ESTIMATES OF UXO IN WATERS TO 120 FEET

In this section, we summarize data collected from previous underwater surveys and oral history information collected from interviews of persons knowledgeable about military operations on Kaho'olawe and surrounding waters. We describe the SCI underwater survey conducted in June 1993, and discuss the effect of buried UXO on any attempt to estimate total UXO. Based on the available data, we provide an estimate of the UXO contamination of the waters surrounding Kaho'olawe.

3.1 Previous Underwater Surveys

A number of limited surveys have been conducted in Kaho'olawe waters which have observed and documented the presence of UXO. No complete underwater survey of Kaho'olawe has ever been conducted for all waters to the 20 fathom depth. The most extensive UXO surveys were those conducted in 1976 and 1978.

List of Past Underwater Surveys;

Marinco Survey of 1976 [7]
Navy Survey of 1978 [8]
Navy Reserve Beach Reconnaissance Survey at Smugglers Cove, 1979 [9]
Navy Reserve Beach Reconnaissance Survey at Smugglers Cove, 1980 [10]
Navy Reserve Beach Reconnaissance Survey at Smugglers Cove, 1982 [11]
Navy Reserve Beach Surveys, North of Kealakahiki Point 1982 [12]
DLNR Aquatic Resources Division, Marine Resource Survey of 1992 [3]
(Note: this was a marine resource survey that incidentally found UXO)

This information is summarized in Table 1 below. Note that these are total sightings. We are not aware if any of the sighted UXO was disposed of. Some of the items may have been sighted in successive surveys. Hawaii Institute of Marine Biology (HIMB) [13] also reported UXO at Waikahalulu Bay (southwest region), Black Rock and Honokoa (west region), and Ahupu Bay (northwest region), but numbers are not available for our summary.

3.2 Oral History Information

We conducted personal interviews or telephone conversations with a wide variety of EOD experts and persons with experience on Kaho'olawe or the nearshore waters. See Appendix A for a list of those interviewed. Many of the EOD

TABLE 1
Sightings of UXO Found in Past Surveys, by Region;

Region	No. Found*	Location of Primary Concentration
West	38	near Kealakahiki & Black Rock
Northwest	5	near Ahupu Bay
North	1	just south of Kuheia
Northeast	0	
East	3	Kanapou
Southeast	0	
South	74	Puu Koae
Southwest	13	Hana Kanaia or "Smugglers Cove"

* These numbers may include multiple counts of the same items.

technicians interviewed have participated in clearance operations in the 1970's and 1980's. The following is a summary of those interviews.

In general, most of the interviewees suggested that from the 1940's through 1960's, UXO landed almost everywhere on the island. In particular, during World War II there were many amphibious assault exercises on the west end near Black Rock, and regular torpedo exercises in Kanapou Bay. In the 1960's and 1970's performance readiness evaluations with live ammunition were routine for ship's gunners before service in Vietnam. Naval gunfire targets near to shore were thought by interviewees to contain high concentrations of UXO projectiles. Targets S-1, S-2, and S-3 on older Target Zone Maps [8] are naval gunfire targets in the North and Northwest Regions.

In the late 1970's the mid-island target zone was established. From that point on, the UXO was more localized to that area. Typically aircraft approached from the north and west to attack "A" targets in the south central portion of the island. Interviewees predicted the presence of bombs along the south cliffs in the vicinity of the target zone. This impression is reinforced by the fact that divers found a 500 lb. bomb last year in Kamohio Bay during the NOAA/HIMB survey [13].

Many of the interviewees mentioned the Rim Pac training exercises of the 1970's & 1980's. These were multinational live ammunition exercises, which complicated the UXO picture with the use of irregular types of UXO. There were reports of pilots occasionally "pickling" (dumping) bombs into the sea if they encountered problems and possible dumping of boxes of unused munitions at sea.

When asked for potential references regarding the numbers dropped, dud rates and locations of UXO, most interviewees said, in effect, "Forget it, the data does not exist." It seems that in most cases, it was never the responsibility of units training on Kaho'olawe to record such data and, if collected, it was seldom held for more than a few years. Several people mentioned the Marine Corps naval gunfire spotting unit at Kaneohe Marine Corps Air Station, the unit responsible to spot for naval gunfire target practice, as a potential source of information. However, these units are no longer stationed in Hawaii and no records were available.

The Ford Island Navy Air Control Command in Pearl Harbor that supported Kaho'olawe operations was also mentioned as a potential source of information. In 1978 they started a program to collect data on the amount of ordnance dropped on Kaho'olawe. The military air traffic controllers only retain 2 years of data in their office on Ford Island, Pearl Harbor Hawaii. No bombing has taken place since 1990 so they no longer have the data in Hawaii. COMNAVAIRPAC in San Diego is responsible for storing all the data. Lt. Col. Bergman, USMC from COMNAVAIRPAC said that they do have data on types of ordnance, numbers dropped, and number of days, but he stated that the data would not be useful to our needs.

The consensus opinion from interviewees was that most UXO would be found near Hana Kanaia, Black Rock, Southwest Point Lighthouse, Puu Koae, Kuheia Bay and Ahupu Bay.

When asked if it was safe to remove UXO underwater by any means other than BIP, all 12 Navy EOD Technicians said "no". Some said that it would be possible to remove small arms munitions but if the UXO is encrusted in coral, they recommended that it be blown in place. The consensus of the Navy EOD technicians was that they would only attempt to move UXO to save a life or valuable equipment.

When asked about what other hazardous materials may be present in Kaho'olawe waters, several participants mentioned white phosphorous munitions as extremely dangerous when brought to the surface and exposed to air. TNT mixed with the phosphorous can scatter it if detonated. This might create a hazardous condition for divers. Other potential hazardous materials are flares within practice torpedoes and practice mines which could ignite during handling.

After describing the general nature of potential remediation operations for Kaho'olawe waters, clearance considerations were discussed. Most respondents said they would first concentrate on clearing areas to afford safe landing for remediation personnel. They mentioned that the good diving around Kaho'olawe will probably attract divers, which increases the need for a thorough UXO clearance before the public is allowed access to the waters. One respondent, Greg Ford, said that "many civilian divers have no idea of the hazard they subject themselves to when they pick up UXO they find underwater."

When buried UXO was discussed, the majority of experts felt that ordnance hitting any but extremely shallow water would be significantly slowed down and would not penetrate the bottom.

When magnetometers were mentioned as a method for searching for buried UXO, the feedback was not encouraging, since a number of technicians said, "It just doesn't work well when you get out at sea".

Dredging operations to clear Pearl Harbor of bombs from World War II were mentioned a number of times. Some of the UXO they attempted to remove exploded in transit, destroying some of the dredging equipment. Another interesting comment by interviewees was that there are always a great many sharks that are attracted to areas where UXO is blown in place underwater.

3.3 SCI Survey

Planning for the underwater survey began during the historical research phase. Historical data and input from EOD experts were combined to produce a survey map. The map includes UXO locations from other underwater surveys, proposed survey regions and sections, known target locations, and other pertinent information that might optimize the survey efforts.

The plan called for surveying approximately 10% of the 7259 acres (total acreage from shore out to 120 feet deep), and 10 days were allocated for the survey. The three major objectives of the survey were to:

1. collect sufficient data to establish a basis for extrapolation of UXO estimates;

2. evaluate detection technologies and;.

3. evaluate environmental parameters that affect UXO clearance operations.

3.3.1 Methods

Planning for the SCI survey began with plotting information from previous surveys and interviews to identify priority search areas. SCI also considered future uses of the water in deciding the priority search areas for best use of resources.

SCI searched the west side first due to its label as the highest risk area by KICC, its importance to future remediation operations, and calm sea conditions. The south side, the approach route for aircraft, was next, followed by the northwest side of the island, including Ahupu Bay, areas used for naval gunfire practice. The survey concluded on the east side near Kanapou Bay where there were torpedo target practice operations, and near Hakioawa where significant archaeological sites are located. Rough sea conditions on both days planned for the southeast region survey made underwater survey impractical.

We employed four principal search methods: towed divers, free swimming divers, towed video and a magnetometer. In shallow waters, skin divers were towed to visually search the bottom for exposed UXO and hazardous wastes over a 30' wide search swath. In deeper waters, or whenever visibility was too poor, SCUBA divers were used. Free swimming divers were also used to thoroughly search smaller selected areas to verify the towed diver search method. A towed video camera system and a magnetometer were tested as potential search methods for UXO. Appendix C discusses the magnetometer survey and its results.

3.3.2 Results

The SCI survey found UXO in most areas reported in previous underwater surveys, such as the high concentration at Black Rock. Table 2 summarizes UXO reported in this survey. We also found other areas of high UXO contamination previously unreported, for example, a total of 11 UXO items were found in the NW region with the highest concentration spreading NE of Lae o Honokoa, to the Makaalae area. In the case of the South region in the Puu Koae area, no UXO was found, contrary to our expectations based on the history of military use and reports from the 1976 and 1978 underwater surveys. This finding is qualified by the fact that on the day of the survey, survey reliability was significantly reduced by rough sea conditions and the presence of new landslide deposits in the area. Stan Ryley, a member of both the SCI survey and the 1978 EODMUONE survey, noted that, in his opinion, the landslides around Puu Koae occurred since 1978. It is possible that recent landslides and/or large waves have partially covered UXO detected during the 1976 and 1978 surveys. By the same token, previously buried UXO may have been oncovered by similar events. A total of five UXO items were found in the South Region, but they were concentrated 1/2 nm west of Puu Koae, in the area just east of Kalama.

We found a total of 76 exposed UXO items in waters to a depth of 120 feet. We searched a total 843 acres which represents 11.6 percent of the total 7,259 acres. The majority of the area searched was in shallow waters, the area assumed to have the highest concentrations of UXO because of close proximity to onshore targets.

TABLE 2
UXO Found in SCI Survey by Region

Region	No. Found	Location of Primary Concentration
West	32	near Kealakahiki & Black Rock
Morthwest	11	northeast of Honokoa to Makaalae
North	4	northeast of Kuheeia near Papakaiki
Northeast	0	
East	4	Kanapou
Southeast	0	
South	5	west of Puu Koae near Kalama
Southwest	20	Hana Kanaia to the Southwest Pt. Light

3.4 Data Sampling, Analysis, and UXO Estimate

3.4.1 Data Methodology and Analysis

The search for underwater UXO can proceed by one of two major methods and many variations of these. The count of UXO could be accomplished by a complete underwater survey with a multitude of sensors or it can be estimated by one of many sampling techniques.

1) The first method is an expensive one for gaining estimates. During actual ordinance removal it must necessarily be redone to insure that all ordnance is removed, thus doubling this expense.

2) The second method, while costing less, is prone to giving estimates that may be over cautious. In this method, we sample a portion of the area, assume it is representative of the whole, then extrapolate the results into the entire region. Time and cost constraints, however, force us to choose this method. Most times sampling is adequate for uses such as this survey; the method should not be denigrated simply because it is not exact. The method is an industry standard.

Data were collected by sampling with different sensors. This analysis will deal exclusively with samples of diver and swimmer observations of exposed UXO and conservative inferences based on these observations. The analysis includes two traditional approaches and a third method designed specifically for the data distribution observed.

The groundwork for accurate sampling is a normal distribution of UXO and a normal, random, unbiased selection of sampling locations.

We have no control over the actual distribution of the UXO. We will assume there is a normal distribution of UXO over very large areas. In addition, we will assume that any departure from this will be accounted for in our statistical analysis. It must be understood that, if a large excess of UXO is sampled, by the laws of chance we will see estimates higher than the true value. Even more disturbing is the possibility of obtaining samples that are low or zero while missing sample sites that are aggregation sites or dump sites for UXO; this causes our estimates to be low. Herein is also the basis for the principle that a good cleanup plan must search the entire area (several times and with several types of sensors.)

The constraint of the random selection also causes unnecessary costs in time, dollars and accuracy. We have taken the position that both our "lack of knowledge" of existing ordnance sites and our "knowledge" of the bottom conditions will allow us to do a quasi-random sampling of the underwater area, yielding equally valid results.

Under nominal conditions sampling 10% to 15% of the bottom would be considered good and should yield meaningful results. However, we have a diversity of conditions, such as: bottom conditions (rock, coral, rubble, mud, sand and silt), water conditions (clarity), observer type (diver and swimmer) and the results of environmental conditions (turbulence, animals), surface conditions (navigation, station keeping), etc. In this case, 10% to 15% of each should be covered.

<u>Regions</u> - We divided the perimeter up into 8 regions denoted by 8 points of the compass (north, northeast, east, . . .) and abbreviated (N, NE, E, . . .). Each of these has several environmental features common throughout the region. There are significant distinctions from region to region. Each of these was analyzed separately. Some (E, NE, N, NW) were undersampled, (S) was adequately sampled and one (SE) wasn't sampled at all.

We analyzed each region separately. In doing so, all of the assumptions made and discussed in the previous paragraphs must apply for each and every region. For example, we must sample at least 10% to 15% of each region. If there are distinct conditions within different areas within the region, we must sample at least 10% to 15% of each of these areas or subregions. We must sample in a random or quasi-random configuration maintaining a normal distribution of sample sites, etc.

Sections - Each region was broken into several sections. For the most part, these ran along the shoreline for a length of approximately 1/2 nautical mile. The depth varied and went from the shoreline out to a depth of 120 feet. Each of these was numbered consecutively (1,2, . . .) for each region. Thus, each section could be identified by a combination of region initial and section number, e.g., W3, NW1, S7, etc.

Swath - Search swaths were chosen in each section. Except for 3 detailed swaths, all the rest were 30 foot wide swaths through the section. The swaths followed the shoreline contour at fixed depths. Depths used were 15, 30, 60, 90 and 120 feet. **The density of UXO in each swath searched defines a SAMPLE.**

Three swaths (mentioned above) were considerably larger than all the others. These were chosen for detailed searches of specific areas. The detailed searches were useful for other purposes and are discussed elsewhere in this report. The data analysis was affected by these samples and the results were skewed by the inclusion of these swaths. This is discussed later in this report.

Other swath configurations were considered during the planning stages of this project, but each proved inefficient or risky. Of these, one was a cookie cutter configuration. Random locations would be chosen, sampled and searched for a fixed radius about the point while the escort boat kept on station. Although a highly accurate method for searching a small area, it is a highly inefficient utilization of the project resources. Another swath we considered was a thin swath perpendicular to the shore line. It automatically includes a search at all depths and an ease of navigation but is innappropriate for a dive profile (divers would be subject to considerable decompression time and the possibility of getting the "bends") and or for control of towed instrumentation.

Many factors were considered before selecting the longshore swath pattern and which of those swaths to sample:

1) There should be absolutely no overlapping of search swaths for the entire survey. This keeps measurements independent.

2) The time economy achievable by running 2 or more consecutive swaths from one section into the next allows more sampling.

3) Keeping the swaths at fixed depth provides increased accuracy by allowing the observer to keep track of the width (e.g. 30 ft) of his observation swath.

4) The boat handler can navigate more easily with longshore swaths than with other track configurations. His main errors will be at the two ends of several contiguous swaths rather than at the two ends of individual swaths. While errors in the positions of the junctures of contiguous swaths can theoretically result in poor data, they did not cause any problem for this search.

5) Boat handling is easier and safer with the chosen method.

Errors that can be caused with the chosen method include:

1) Restricting the search to a small number of discrete depths means that some depths are overlooked. This means that the search is <u>not a totally random search</u>. In this case we assume that the random entry of UXO into the waters and the uniform slope in most regions negated any error from the small (quasi-random) choice of depths. The bathymetry was also favorable.

2) Doing several contiguous searches can cause observer fatigue and poor perfomrance. For this survey, the time was not long enough for this to be a factor.

In general, the main factor affecting the accuracy of the sampled search performed (for proud UXO) was the undersampling of some regions. If we had more resources or if we had been able to spread the resources more evenly around the island (in reasonable constant swath areas), the results <u>might</u> have been more definitive for <u>some</u> regions.

<u>Inferences</u> - We expected to base our estimates of hidden (buried) UXO on magnetometer data (discussed elsewhere in this report). The lack of this information forced us to infer this information based on the following reasonable hypothesis.

The observers could only count the exposed UXO on the hard surfaces (rock, coral, and some heavy rubble surfaces) and not those buried under the compliant surfaces (sand, silt, mud, and light rubble) and slide zones. We inferred in each swath that the density of UXO initially deposited on the hard surfaces was the same as that initially deposited on the compliant surfaces. This is equivalent to UXO in each swath being normally distributed and all (100%) of the UXO initially deposited on the compliant surfaces ultimately becoming buried. While this assumption is not entirely true, it gives a reasonably conservative estimate of total UXO.

One drawback of this assumption is that we must find some UXO on the exposed surfaces to proceed with the extrapolation. Results for compliant bottoms could only be inferred when data were available from the hard surfaces.

Uniform vs Normal & Random - For sampling to be effective, the distribution of sampling points should be random and normally distributed throughout the region. For those regions that were adequately sampled because of the large percentage of area searched, we feel that the distribution of sampled swaths had no effect on the outcome. The undersampled regions also had poor distribution. Estimates for those regions are more suspect.

Data Analysis - Three studies were initiated to extrapolate the collected data into the entire surrounding waters; each has some validity. We will not attempt to justify one rather than the other. Only the first study was completed but information from the other two studies is presented and can be used to modify interpretation of the results. If desired, the last two studies could be completed with a modest amount of additional funding. The basis of the three studies starts with estimates from the actual data counts:

1) Average - The first study takes the simple ratio of the total UXO found and divides by the area sampled. It assumes that the same ratio (density of UXO) will be true for the entire region. This method uses no sampling theory nor statistical inferences. Our cost estimates are based on this. Time restrictions forced us to use this as a basis for many calculations.

2) T-Test - The UXO density of each sample was computed. The average of these densities is the expected density of the region. This is significantly different than the first study above and is a better estimator of the average UXO density. The standard T-Test was applied to these data to estimate how big (or how small) the UXO density might be with respect to given confidence levels. This method takes into account that some samples were zero and others had different values (but it is based on an assumed normal distribution of densities.) The T-Test is designed for data sets much different than ours, but it is frequently used on this type of data since it is such a "robust" tool.

3) Poisson Distribution - The UXO density of each sample was computed. The average of these densities is the expected density of the region. As with the second study, this is significantly different from the first method and is a better estimator of the average UXO density. We assume that the data reasonably follows a Poisson distribution (exponential decay). This distribution was chosen as the simplest one-parameter family of curves that has the same characteristics as the data. We again analyzed the data with respect to this distribution to estimate how big (and how small) the average density might be with respect to given confidence levels. This method takes into account that most samples were zero,

others had different values, and none had negative values. It also assumes that large sampled densities are less frequent than small or zero densities.

The three methods were applied to the data taken. The data taken are the actual count of observed UXO. Each of the above methods was used to extrapolate the raw data into the unsampled region. We must first estimate what UXO were missed in the sampled regions. There are two extrapolations which must be performed.

3.4.2 Extrapolations

We first did two extrapolations common to all three analyses to account for UXO that were possibly missed by the observers. The first is an extrapolation to correct for observer error and the second is to correct for hidden UXO. These were both done under the assumption of a perfect sampling technique and results. The appendix contains seven spreadsheets, one for each region. The calculations described below were used to produce those sheets.

Extrapolating for Diver Misses

The raw data (number of UXO) are reported by the diver for each swath. The diver also reports, for each and every swath, his ability to detect proud UXO. This is e e expressed as % OBSV_PROUD. A value of 90% indicates the observer would find 90% of the proud UXO in the swath and would miss 10% because of one or more of many factors. These factors include visibility, bottom conditions (coral growth), etc.

For the region results (AVERAGE ANALYSIS), we normalize this percentage weighted by the area of the swath in the normal way, using a normalization factor calcualted as the ratio of two sums. The numerator is the sum of the products of the swath areas times the observer detection percent (%OBSV_PROUD). The denominator is the sum of the sampled swath areas (the total area searched).

The number of proud UXO for the region is the number counted divided by this ratio. This is an estimate of the number of proud UXO that would have been sampled had the observers had perfect (100%) sensing.

For the sampled analysis, the data for each swath are adjusted similarly by dividing by the (%OBSV_PROUD) for each individual swath. The sampling analysis will later average these densities.

Common to all the analyses is a method to account for observer "misses."

3.4.3 Extrapolation for Hidden UXO

The observers also report on the bottom conditions. Since they can only see exposed items, we must estimate what is buried. We use the assumption that the distribution of UXO is the same whether it is buried under the soft bottoms or proud on the hard bottoms. The observer estimates the percent rock bottom, the percent hard coral bottom, the percent rubble bottom, the percent sand bottom and the percent silt bottom for each swath. We divide these into two exclusive categories, hard bottoms that have only proud UXO and soft bottoms that have only buried UXO. For each swath we add the percent rock, the percent coral and one-half percent rubble; this is the percent hard bottom. For each swath we add the remainder, the percent sand, the percent silt or mud, and one half the percent rubble; this becomes the percent soft bottom. The percent hard bottom plus the percent soft bottom equals 100%.

As in the previous extrapolation (Average Analysis), we use a weighted average of these samples to get the percent hard bottom for the sampled part of the region. The region percent hard is the ratio of two sums. The numerator is the sum of the products of swath area multiplied by the swath percent hard bottom. The denominator is the sum of the swath areas (the total area sampled).

The total number of UXO in the sampled region is estimated to be the number of expected proud UXO divided by the percent hard bottom.

For both of the sampled analyses, we extrapolate swath by swath, dividing the proud density by the percent hard bottom for the swath. The adjusted densities can then be analyzed as a corrected data set.

3.4.4 Analysis

To repeat, this analysis throws all the swath data from each region into one swath, as if there were no sampling. The following discussion pertains to this method only and uses the two extrapolations given above to account for data missed in this one big sample swath.

We now have three numbers that describe the UXO in the sampled part of each region; the actual count, the expected number of proud UXO, and the total number of UXO. These are representative of the region. We have two percentages that are weighted averages over the sampled areas. The average percent the observer believes he can detect and the percent hard bottom. We consider that we have adequately sampled these two items and assume these to be constant over the entire region.

Under the assumption of constancy of the detection percent and bottom condition percent, we can extrapolate into the unsampled part of each region. We divide the three UXO counts of the previous paragraph by the sampled area and get counts per acre for each. These are the densities of OBSERVED, PROUD and TOTAL for each region. We then multiply by the total area of each region to get the count for each region. We have not used any statistics involving sampled data. We have used weighted averages of detection criteria to extrapolate for missing data in each swath.

Area Analysis Results

The main results for this (AVERAGE ANALYSIS) are shown in Table 3.

TABLE 3
Results of Analysis 1: Area Analysis

REGION		SW	S	E	NE	N	NW	W	SE
SAMPLED AREA, TOTAL AREA, COVERAGE									
SAMP AREA	ACRE	303	67.0	11.5	15.7	37.5	49.2	360	0
REGION A.	ACRE	1144	303	332	783	1043	942	2276	436
% SAMPLED	%	26.5	22.1	3.47	2.00	3.60	5.22	15.8	0
NUMBER OF UXO IN SAMPLED AREAS									
COUNT	#UXO	20	5	4	0	4	11	32	N.A.
PROUD	#UXO	23.5	6.2	4.7	N.A.	4.4	13.3	34.0	N.A.
TOTAL	#UXO	131.7	8.5	5.6	N.A.	11.7	32.5	43.8	N.A.
NUMBER OF UXO PER ACRE									
COUNT	#/ACRE	.066	.075	.348	N.A.	.107	.224	.089	N.A.
PROUD	#/ACRE	.078	.092	.405	N.A.	.118	.270	.094	N.A.
TOTAL	#/ACRE	.435	.128	.485	N.A.	.312	.662	.122	N.A.
NUMBER OF UXO PREDICTED IN REGION									
COUNT	#UXO	75.6	22.6	115.4	N.A.	111.2	210.7	202.5	N.A.
PROUD	#UXO	88.9	28.0	134.3	N.A.	122.8	254.6	215.0	N.A.
TOTAL	#UXO	497.9	38.6	161.0	N.A.	325.4	623.3	277.3	N.A.
NORMALIZED PERCENTS FOR DETECTION AND HARD BOTTOM									
%PROUD	%	85.1	80.8	85.9	91.3	90.5	82.8	94.2	N.A.
%HARD	%	17.9	72.5	83.4	31.0	37.8	40.9	77.5	N.A.
REGION		SW	S	E	NE	N	NW	W	SE

In the east, north, and northwest regions we should expect a total of 161, 325 and 623 UXO respectively. This is a total of 1109 UXO with no estimate of the confidence level.

In the southwest, south, and west regions we should expect a total of 498, 39, and 277 UXO respectively. This is a total of 814 UXO with no estimate of confidence level. We expect these numbers to be more accurate because of the larger area searched.

In the southeast region we have no data; nothing can be said definitively about this region. Any estimate made by interpolating or extrapolating data from adjoining regions is of questionable value. The adjoining regions have their own characteristics.

In the northeast region we found no UXO but only sampled 2% of the region; nothing can be said with any accuracy. Any estimate made by interpolating or extrapolating data from adjoining regions is of questionable value. The adjoining regions have their own characteristics.

TABLE 4
Average Estimates of UXO By Region

REGION	SW	S	SE	E	NE*	N	NW	W
PROUD	89	28	**	134	*	123	255	215
TOTAL	498	39	**	161	*	325	623	277

(*) No UXO found in undersampled region NE, extrapolations are invalid and are not shown.

(**) No data taken in SE region.

Results for the SDA (Special Development Area, see p. xiii, 5 - 5) zones are presented below. These were estimated from the regional densities and the areas of the zones.

TABLE 5
Results for SDA Zones

REGION	KUHE-	KU-EX	HAKLO	KANAP	KAMO-	HA KA-	HONO-	AHUPU
LOCATION	N	N	NE*	E	S	SW/W	W	NW
PROUD	20	7	N.A.	60	2	241	6	23
TOTAL	52	17	N.A.	72	2	550	8	58

* Data in the NE sector were too skewed for valid extrapolation.

Since disposal cost estimates depend on the UXO being proud or buried, all cost estimates should refer to the above 3 charts.

3.4.5 Sampling Studies

Only the observed data were completely analyzed at the time of this report. The number of proud and the total for each region was prepared for analysis and can be completed at a nominal cost. The results are illustrated by two charts. Each region on the chart is represented by a horizontal display. The display is in terms of UXO density (UXO/ACRE). Actual counts of UXO can be obtained by multiplying these densities by the appropriate area. From this display we can compare the statistics from region to region. We can also compare the sampling result to the average analysis.

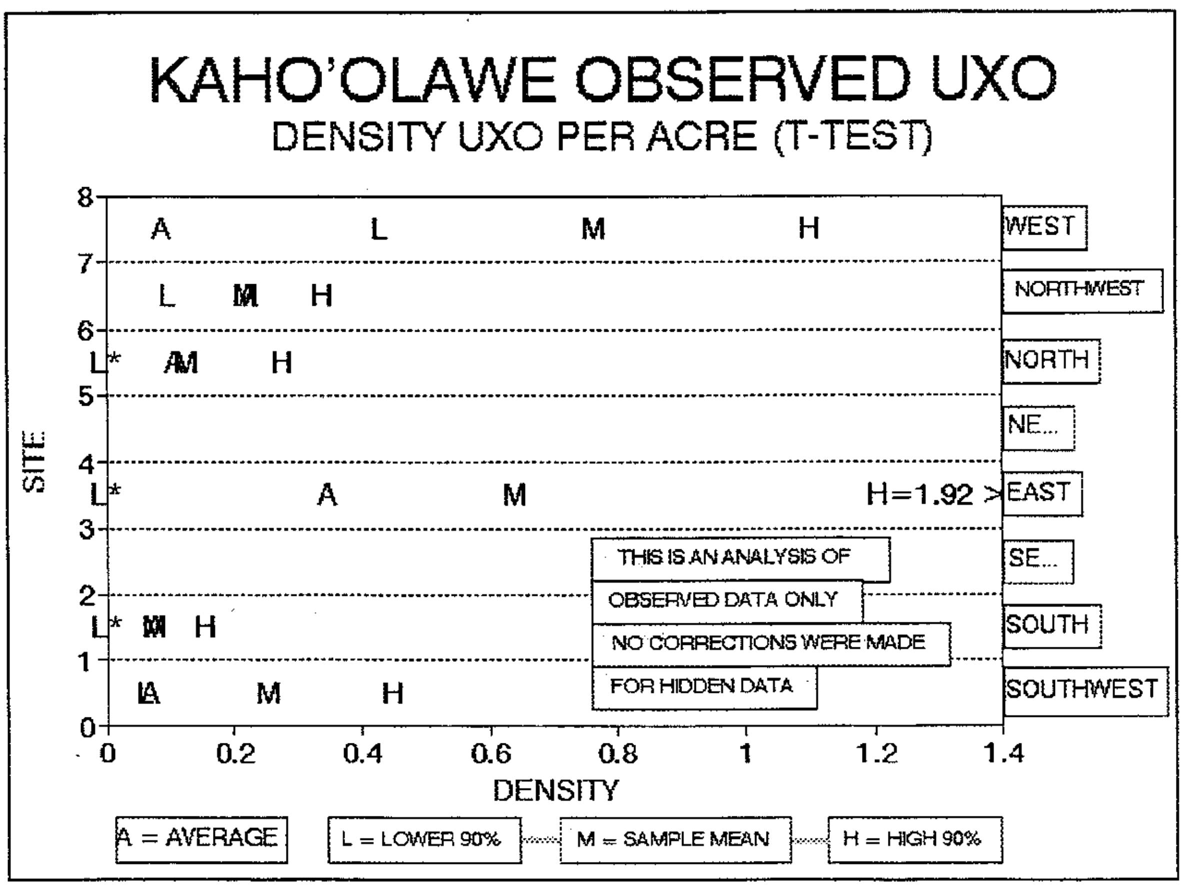
There are 4 letters in each row. Each represents a density.

- A Average from the Average Analysis used in the previous results. This treats all the data in each region as if it were all taken in a single swath; that is, unsampled.
- M The mean density considering the data as sampled data.
- L The lowest estimate of the density expected at a 90% confidence level.
- H The highest estimate of the density expected at a 90% confidence level.

All of the above information should be used for a complete study of the logistics of UXO remediation.

<u>T-Test Results</u>

The following chart represents the raw data as analyzed using the T-Test. Although the data sets are not normally required for using the T-Test, the results are shown following the industry standard.



The three points labeled L* (lowest 90% estimate) lie on the negative axis. This is a physical impossibility but is a result attributed to the T-Test model. We have reset these to zero.

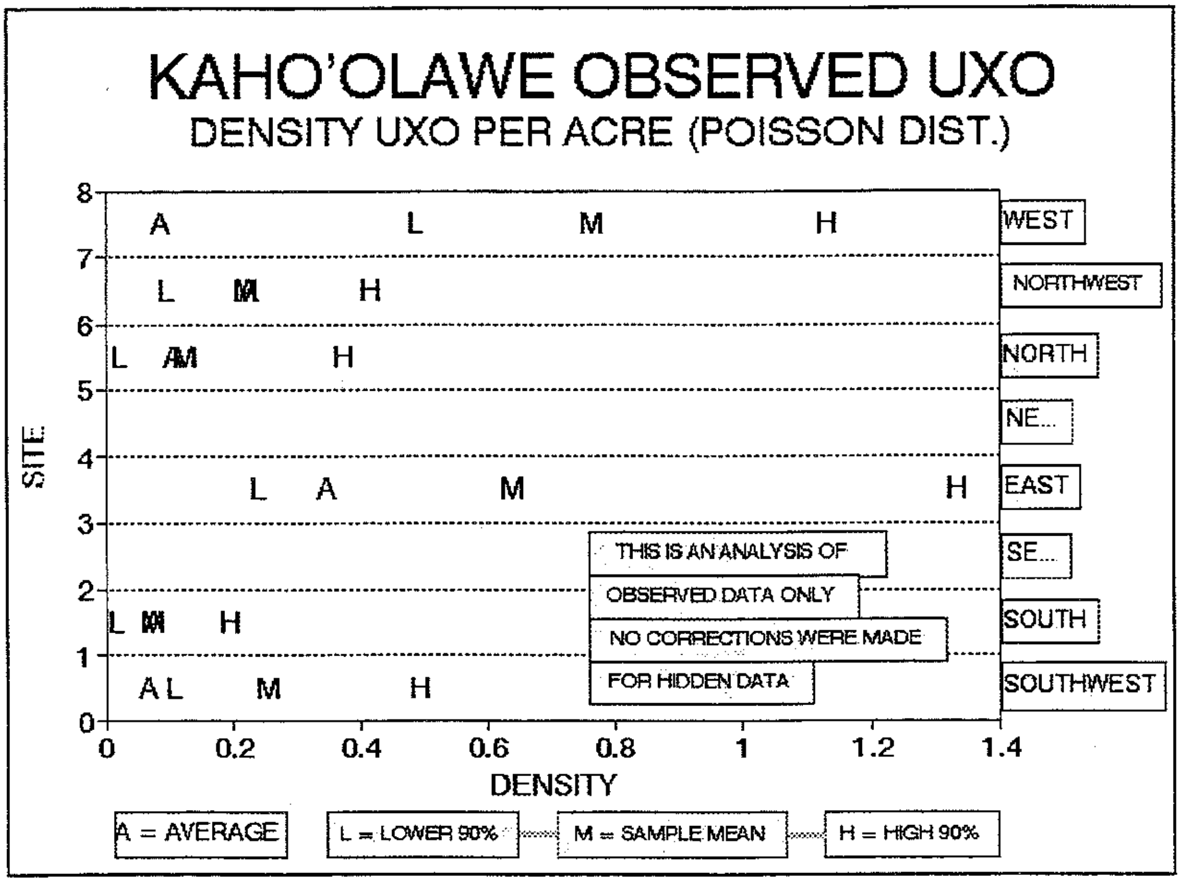
The East value for H (highest 90% estimate) lies offscale. Its value is 1.92. The graphs were not rescaled for this point so as to keep the other results reasonably spaced.

The large difference in A and M for the West (and SOUTHWEST) is due to the biasing of two large sample areas.

A similar analysis should be done for the Proud density and the Total density.

<u>Poisson Distribution Results</u>

The following chart represents the raw data as analyzed using a Poisson Distribution as a model for the data set. This was developed specifically for this experiment and is more appropriate than the T-Test.



The large difference in A and M for the West (and SOUTHWEST) is due to the biasing of two large sample areas.

A similar analysis should be done for the proud density and the total density.

4.0 POSSIBLE CLEARANCE TECHNOLOGIES

4.1 Navigation and Communications Systems

For all detection and remediation activities, it will be important to have extremely accurate (to within 1 meter) navigation systems and voice/data communications systems. The most cost-effective approach would be for land-side and ocean clearance activities to share the major navigation and communication systems. In addition, ocean clearance activities have special requirements for underwater and towed instrument navigation, which must be integrated with the main navigation system.

Data can be organized by a Geographical Information System (GIS), which allows detection and remediation activities to record, report and analyze data using overlapping maps.

The following are systems and technologies that may be used.

4.1.1 Differential Global Positioning System (DGPS)

The Global Positioning System (GPS) and the Differential GPS (DGPS) depend on the use of satellite signals from the Block 1 and Block II NAVSTAR satellites to calculate position.

The Department of Defense (DoD) has a policy of Selective Availability (SA) for the newer Block II satellites, which intentionally degrades the accuracy of GPS time and position signals. Access to the full precision signals is available only to authorized (usually military) users with the encryption code key.

Fortunately, SA can be corrected by the use of fixed reference stations operating simultaneously in the area of interest. The errors introduced by SA are detected at the fixed stations, and the reference station generates a correction signal which is broadcast by a small local transmitter. GPS receivers equipped with Differential GPS (DGPS) capability combine the correction signal with the GPS data to achieve sub-meter position accuracy and ~100 nanosecond timing accuracy.

There is a problem if visibility to one of the GPS satellites or to the DGPS transmitter is blocked by cliffs. In such cases it may be necessary to have more than one DGPS transmitter, or a supplemental short-range line-of-sight navigation system, such as the Motorola Mini-Ranger, to fully cover the search area.

4.1.2 The Motorola Mini Ranger

The Motorola Mini Ranger has been used in a number of land and sea survey operations. The Mini Ranger relies on a system of two reference station transponders at known positions and a mobile transponder, all within line of sight of one another. The system computes ranges by sending signals to all three transponders, and computing the distances between them by measuring the time it takes for the signal to cover the distances. It calculates a position which is transmitted to the mobile unit and command station on shore. The system is accurate to within 1 meter on the surface of the water, and has proven reliability for the navigation of small craft at sea. It is capable of providing steering information to a boat driver down selected search grid lanes, or it can simply direct the driver to a position.

4.1.3 Underwater Navigation

An underwater navigation system may provide the most accurate type of location information for mapping UXO since it relies upon the diver's actual location underwater rather than the location extrapolated using the navigation system in the boat, positioned directly over the diver. Underwater positions are nominally 3-dimensional; however, in the nearshore shallow-water environment the depth is easily available through traditional depth sensors or acoustic altimeters, so the navigation problem simplifies to 2 dimensions.

None of the navigation aids that use the radio frequencies of the electromagnetic spectrum (DGPS, Loran-C, Mini-Ranger) can be used underwater; these frequencies are attenuated by sea water. Various systems are available that use short-range acoustic transponders to derive a position underwater relative to a known base station (usually installed on an anchored boat or buoy).

Long baseline (LBL) systems use an array of transponders or pingers with spacing of .1 to 10 km. The range-range accuracy can be <1 meter, or 1 cm over a range of 100 meters.

Short baseline (SBL) and Ultra-short baseline (USBL) systems use direction, time of arrival, and phase. Both range and heading information is provided. Accuracy is claimed to be 1 meter and 1 degree in commercially-available systems, but these "range-bearing" systems are inherently less precise than range-range calculations.

Inertial navigation systems are becoming smaller and cheaper; an inertial package may become part of a diver navigation system. The inertial data can provide short-term position and velocity which are combined with the acoustic data for higher resolution and accuracy.

Another system useful for towed video and towed divers is Doppler sonar which provides a continuous measurement of speed. EDO Acoustics manufactures a miniature electronics and doppler head, normally used for ROVs, which uses Doppler sonar for estimating speed relative to a scattering surface (the bottom). Positions obtained by integrating the speed measurements yield errors less than 1% of the distance traveled.

There are reports of an underwater navigation system being tested by the Operational Testing and Evaluation Center for Ocean Research (OPTEVFOR). This system uses a network of 4 underwater beacons as acoustic references for a diver held navigation board. Such a system may enable a diver to swim his own search pattern grid without relying on a tether to the surface to track his location. The use of such a system depends on testing results and availability of the equipment.

4.1.4 Geographic Information System (GIS)

Once all the various types of information are collected, it is important to be able to graphically map their locations and be able to navigate back to the exact spots. A Geographic Information System (GIS) provides a mechanism for recording data from the navigation and data communications systems, and plotting them on a map. Multiple data sets, organized as maps, can be overlaid and compared. The Data Acquisition and Navigation System (DANS) for geophysical surveying and mapping is available for above-water use.

4.2 Detection

A strategy for detecting UXO in the underwater environment must consider the strengths and limitations of natural sensory systems and man-made technologies that use acoustic, electric, magnetic, or electromagnetic fields. There are many different possible shapes and sizes of objects to be detected, in many different bottom types, depths, water clarity, and sea conditions. Some UXO is buried, and cannot be seen at all. Some has been colonized by coral and other organisms, its shape and color camouflaged beyond recognition. Each of the detection techniques listed here may be useful in appropriate conditions.

The high electrical conductivity of seawater leads to rapid attenuation of electric and electromagnetic fields (e-m) in seawater, which limits the range of their applicability. For this reason, acoustic waves are frequently chosen for seawater imaging and data transmission. Since acoustic waves are inherently lower frequency and longer wavelength than light and other e-m emissions, and since shorter wavelengths are more dramatically attenuated, low resolution is a major limitation of acoustic imaging systems.

After analyzing the advantages and disadvantages of the technologies summarized in the following pages, SCI has developed the following proposed detection scenario:

1) A magnetometer survey will first be conducted using a proton precession magnetometer towed in a vehicle with precise depth control and a precision navigation system to provide accurate locations. Survey tracks will be designed to follow specific contours at a fixed height off the bottom, thus providing complete coverage of the waters all around the island. Following a significant data reduction effort, this survey will provide locations of all concentrations of ferrous metal, buried and exposed, around the island.

2) The final detection effort will be conducted in conjunction with remediation for successive clearance areas progressing around the island. The sequence of areas to be cleared will be determined by a complex decision matrix incorporating desired uses of the areas, suspected concentrations of ordnance as determined from historical records and the magnetometer survey, and the availability of appropriate detection and remediation resources.

3) Detection will be accomplished using a combination of underwater video, divers and marine mammals. Selection of the appropriate system will be based upon efficacy and economics. Video systems are least expensive, but will only detect some of the unburied ordnance. Divers, more expensive to deploy, will detect a larger percentage of the exposed UXO. Depending upon the substrate and the amount of coral encrustation they will miss some, however, and they can only detect buried UXO at specific sites with handheld magnetometers. The dolphin object location and marking system will provide an essential part of the detection effort by detecting and marking remaining significant un-buried and buried UXO in the area. The time required for this most expensive component of the detection process will be significantly reduced because of the preliminary information from the magnetometer, video and diver systems.

4.2.1 The Human Eye

No current technology can approach the capability of a human eye and brain in recognizing a variety of shapes in a field of clutter. An experienced human swimmer or diver can see proud (exposed) UXO and discriminate it from the surrounding rock, coral, and rubble. Sometimes shape is the only useful cue, since the natural camouflaging usually matches the color of the surroundings.

In shallow waters during calm weather, a skin diver towed on a surface sled from a rigid inflatable boat works best. When the skin diver sees suspected UXO, he can release the sled and inspect for UXO. When items are found, they can be marked off with floats for identification and prosecution by the EOD teams. In deeper waters, the most effective detection system will use a two man sled that has a voice link to the surface for communications. When UXO is sighted, the sled pilot will tell the boat driver to pause while the sweep diver swims over to the UXO and deploys the float marking system. The location and suspected type of UXO will be recorded using the data communication and navigation system, and then the boat and sled will continue searching the section.

One limitation of human divers is the 'bottom-time' available for each individual diver. Cumulative effects of absorption of nitrogen from compressed-air diving limits the time that a diver can remain at depth each day. Personnel on a boat should alternate diving and other functional tasks to most efficiently conserve their limited bottom-time.

4.2.2 Towed Video

A towed video camera system is an excellent alternative to divers in deeper waters where there is less clutter, less UXO covered by shifting substrate movements, and less marine growth. The use of video is a kind of 'telepresence', allowing the human observer to view the bottom as if he were actually there, while physically remaining at the surface, conserving bottom-time.

The task of visually recognizing UXO is more difficult using video, compared to viewing directly. The resolution and range of color is limited, and the motion of the image causes viewing fatigue, since the observer can't compensate for the motion as he would normally do in situ by using his body orientation sense. There are also scan line artifacts because of the way video fields are interlaced to make up a frame. While conventional single-camera underwater video systems can be used to identify UXO in perfect conditions, it is much more difficult under poor visibility and where the UXO may be nestled in a surrounding substrate of coral or rubble.

New developments in economical stereoscopic displays make it practical for a towed video system to use stereo. The extra information provided by stereo vision for complex scenes and ambiguous objects drastically improves performance on recognition and telepresence tasks [14]. The harder the task, the greater the benefit of using the stereoscopic video [15].

Visual cues for distance and shape can be divided into three sorts: monocular cues, which are cues present in the image of either eye independently; oculomotor cues, which include focus accommodation and convergence (the inward turning angle of the eyes toward a nearby object); and binocular disparity cues, or stereopsis.

The monocular cues include: superposition (a closer object obscures part of one farther away); 'aerial perspective' (objects farther away are hazier and bluer);

receding parallel lines (if there are objects in the scene which are known to have parallel lines); shadows; size in the image (if size of the object is known), and monocular movement parallax (the relative motion of nearby and far objects as the viewpoint moves). These cues are available from the conventional single-camera underwater video system.

Focus accommodation and convergence are oculomotor feedback cues. The muscles controlling focus of the eyes and orientation of the eyes converging on a nearby object provide information about the distance to the object. These cues are missing in a single camera video system.

The most important cue, binocular disparity, provides information about depth and shape by the comparison of the overlapping fields of vision of the two eyes. This comparison takes place in the brain, and is sometimes called "cyclopean perception", since it provides an additional vision sense, like the mythical Cyclops' eye, not provided by either eye individually. The binocular disparity effect is due to the distance between the eyes, approximately 5 cm. Using binoculars, stereo microscopes, special optical instruments, or camera rigs, one can increase or decrease this distance, to increase the disparity, or to decrease it.

A stereoscopic image appears subjectively clearer than a monoscopic image with the same signal/noise ratio and brightness. Partly, this is because of the additive effect of two independent similar images - the images sum while the un-correlated noise and backscatter do not. The stereopsis effect adds additional rejection of noise and backscatter by allowing depth discrimination between noise and objects of interest.

4.2.3 Scanned Laser Imaging System

Scanned laser systems are similar in purpose to a video camera system. The scanned laser system, or flying spot scanner, can be thought of as a backwards video camera. Using a normal video camera, an entire scene is illuminated by light, which bounces off the objects in the scene, and is collected by a lens. The lens forms a 2-dimensional image on the face of a CCD image sensor or image tube. The CCD or tube is then scanned, so that the image is converted to an electrical signal one line at a time, and it comes out on a wire as a video signal.

The flying spot scanner works by scanning a very bright thin light beam (the laser) one line at a time across the scene. For underwater use, the laser must have most of its energy in the blue-green passband of seawater, near 550 nm; possible laser types include argon, Nd:YAG, or solid-state thulium/erbium/praseodmium (TEP). The light bounces off whatever part of the scene the "flying spot" happens to hit at that moment, and is collected by one or several photodetectors. If there is more than one photodetector, all of the detectors add together. The photodetectors convert the received photons into an electrical signal, and it comes out on a wire as a video signal, just like a normal camera.

Visually, the position of the laser scanner is like the position of the camera - it is the viewpoint that we see the image from. The position of the photodetectors is like the position of the light sources - wherever there was a photodetector, it "looks" like there was light coming from that position.

The advantage of the scanned laser system over a video camera system is that, theoretically, performance in turbid water can be improved. In turbid water, the particles in the water scatter light, which reduces contrast in the image. By reducing the amount of water volume shared between light and camera, or between photodetector and scanning laser, the backscatter can be reduced. This is more important in deep water, where artificial illumination is required.

Science Applications International Corporation (SAIC) has a prototype argon laser scanner that they have proposed to demonstrate in Kaho'olawe waters. This technology may be especially appropriate for large area video mapping, to create a visual map overlay to combine with other sensor data.

4.2.4 Sidescan Sonar

Sidescan sonar uses a towed sonar transducer with a directionally-shaped sound beam. The beam is a line shape (wide vertically and narrow horizontally) that repeatedly scans perpendicular to the track of the towed 'fish' to build up a picture of the bottom. Usually two-sided units are used to build a picture of both sides of the track.

Towed sidescan sonars are available in many different configurations. High-resolution, high-frequency systems can resolve centimeter-sized detail over a swath width of 100-200 meters. Low-frequency systems can resolve meter-sized detail over a swath width of 2 km.

Sidescan pictures are very limited in what they portray of the actual objects on the bottom. Light and dark areas of the image represent areas of high and low acoustic reflectivity which can be severely confounded by irregular shapes, surfaces, and material composition of the actual objects being viewed. High-frequency sidescan sonar may be useful for searching areas of poor water clarity, with a relatively shallow slope and minimum clutter from coral, rubble, and rocks. Exposed UXO on smooth sand, mud, or silt bottoms may be recognizable on the display.

4.2.5 Pulse Imaging Sonar

Arete', sponsored by Navy and ARPA research contracts, has developed technology for broadband, sparse-array, nearfield acoustic imaging. The technology uses a small array of hydrophones to receive echoes from a broadband chirp or ping. The multiple hydrophone signals received are digitized and processed by the near-field sparse-array software to create an image showing relative echo return strengths.

The system currently is in research and development, and not fully operational. The technique is sensitive to variations in altitude above bottom, and clutter. After more development, the system may be useful for finding UXO covered by up to 6 feet of uniform sand or silt in extremely shallow calm water.

4.2.6 Magnetometer

Magnetometers have been highly developed for both marine geophysical and treasure hunting uses. The geophysicists routinely deploy magnetometers from ships and planes to measure the earth's magnetic field. Regular patterns of spatial variations (anomalies) in this field are now believed to be caused by past reversals of the earth's magnetic field being "frozen" in the seafloor rocks as they cooled at the mid-ocean ridges and were then moved horizontally across the ocean basins by sea floor spreading. The magnetic evidence thus collected has been one of the primary pieces of evidence for the highly successful theory of plate tectonics.

Treasure hunters have found that magnetometers work better than metal detectors for discovering old wrecks, because magnetometers have longer range in seawater and most wrecks have some ferromagnetic components.

There are basically two types of magnetometer available today: the "proton precession" and the "fluxgate". Other devices, using hall effect semiconductors and other phenomena, have inadequate sensitivity for general survey operation.

The proton precession magnetometer uses a sensor "bottle" filled with a fluid, such as water or hydrocarbons, which contains hydrogen nuclei. A coil surrounding this bottle is energized with direct current, creating a magnetic field throughout the sensor fluid. This magnetic field orients the spins of all the protons in the fluid in the same direction. When the electric current, and thus the magnetic field, is switched off, the protons begin to wobble or "precess" like tops. The precession is at a frequency determined solely by the external magnetic field surrounding the instrument, and it generates a signal which is "picked up" by the same coil which provided the energizing field and can be counted by a frequency counter. The frequency is directly physically related to the field being measured, so the only calibration required for such an instrument is that of the electronic counter.

The proton precession magnetometer measures the total scalar magnetic field at the site of the sensor, independent of the vector direction. Only the strength, not the frequency, of the oscillatory signal generated by the "wobbling" protons is affected by the relative direction of the external field. The total field is proportional only to the frequency, so measurement of the frequency provides an absolute measurement of the total field. The frequency measurement will only be compromised when the signal is too weak for the counter to determine the frequency. Weak signals can be caused, for example, when the gradient of the surrounding field is so steep that the protons in different parts of the sensor precess at different frequencies so that the sum of the precession signals is reduced by interference.

Though the direction of the magnetic field vector at a site will provide additional information about what might be causing variations in the field, practical difficulties preclude the use of directional fluxgate magnetometers for marine surveys. First, existing fluxgate designs are about two orders of magnitude less sensitive than standard proton precession systems. The other main problem is that vector (strength and direction) measurements depend on precise knowledge of the orientation of the sensor. Typical marine survey operations involve towing the sensor behind a vessel, and stable tow configurations are extremely difficult to achieve. A successful vector measurement system will require complex position determination equipment and a position correction algorithm to permit determination of the absolute vector direction.[16]

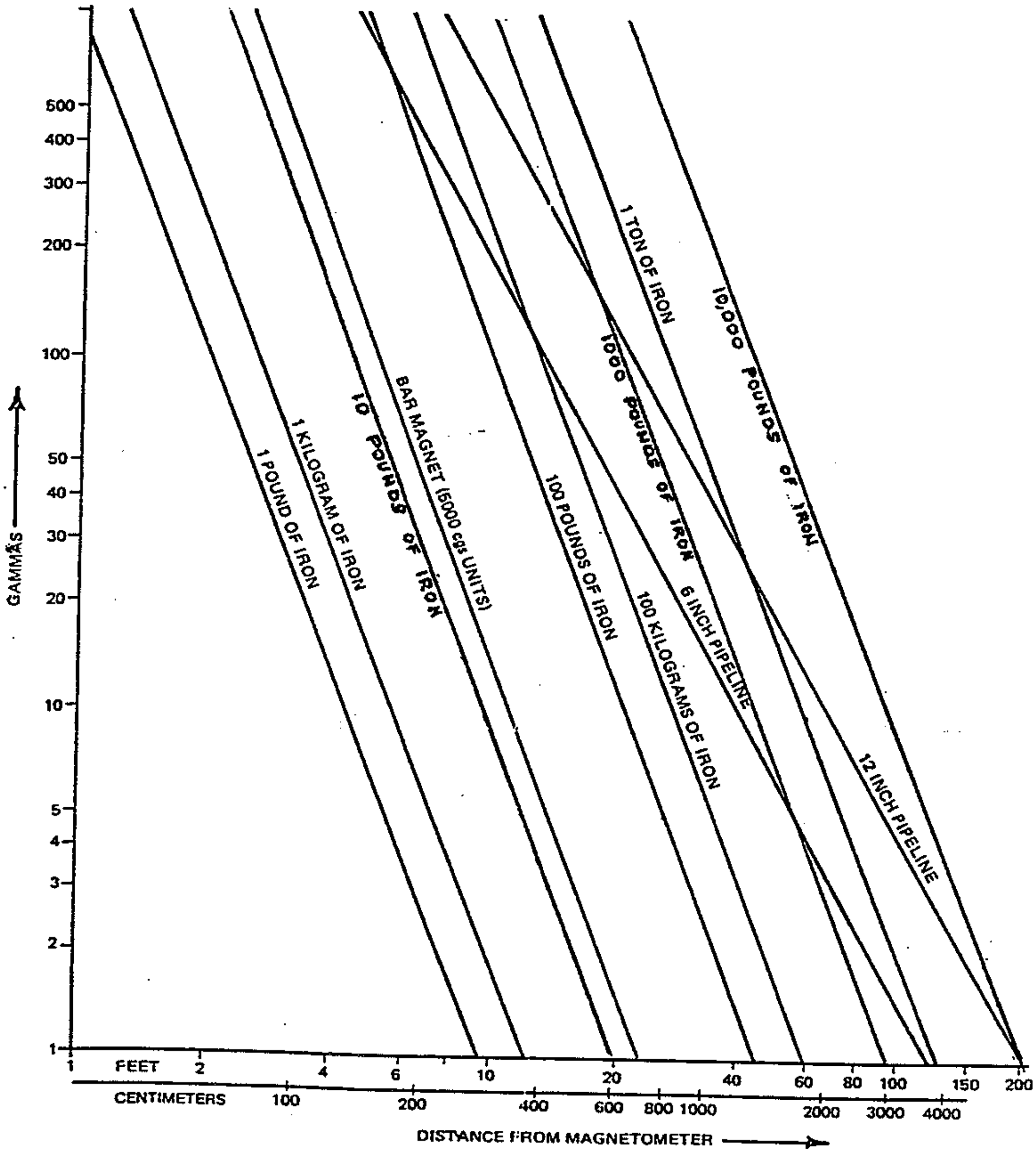
A fluxgate design developed recently by EMDS of Gaithersburg, Maryland boasts about the same sensitivity as proton precession magnetometers, but it is highly developmental and has not yet been built into an appropriate marine housing. This system might prove suitable for future magnetometer surveys, once it is more fully developed and integrated into a tow system with adequate positional control.

4.2.5.1 Magnetometer Search Parameters and Techniques

The magnetic signal strength is generally proportional to the mass of iron in an object and decreases with the cube of the distance from the object, so detectability of an object is a complex function of its distance from the sensor and the mass of iron it contains. It is important to note that the signal from even a very large object will only persist over a relatively short distance. Figure 1 shows the magnetic field strength expected as a function of distance from various objects. Though proton precession magnetometers typically have sensitivities of 1 nT, an anomaly greater than 10 nT is typically required for detection.

FIGURE 1

Nomogram for Estimating Anomalies from Typical Objects (assuming dipole moment M = 5 X 10⁵ cgs/ton, i.e., k = 8 cgs. Estimates valid only within order of magnitude)



INSTRUCTIONS FOR USE:

To use the nomogram, select a given weight or type of object from among the diagonal labeled lines. Then choose a distance along the bottom line (abscissa) of the graph and follow a vertical line upwards from that distance until it intersects the diagonal line of the selected object. At that point, move horizontally to the left to a value on the vertical axis (ordinate) of the graph and read the intensity in gammas.

At a given distance, the intensity is proportional to the weight of the object. Therefore, for an object whose weight is not precisely that of the labeled lines, simply multiply the intensity in gammas by the ratio of the desired weight to the labeled weight on the graph. If the distance desired does not appear on the graph, remember that for a typical object the intensity is inversely proportional to the cube of the distance and for a long pipeline the intensity is inversely proportional to the square of the distance between magnetometer sensor and object. Due to the many uncertainties described herein, the estimates derived from this nomogram may be larger or smaller by a factor of 2 to 5 or perhaps more.

(reproduced in modified form, by permission from Applications Manual for Portable Magnetometers)

Sensitivity of the magnetometer depends upon the excitation/measurement cycle length and, to a small extent, on the direction of passage over the object being detected. SCI found that the manufacturer's recommendation of a 2-second cycle (one second excitation, one second measurement) worked well for the shallow waters around Kaho'olawe. No other cycle options were tested. Detailed surveys with multiple crossings of suspect objects can produce contour plots of the magnetic field intensity over an area. Analysis of these can yield particulars of the mass of iron and the extent of the objects causing the anomalies. The theory of such classification is covered in various references [17][18]. The signal received from any single crossing of an object cannot define its size, since there is no information about how far the sensor is from the object or even on which side of the vessel track the object lies. Most iron containing objects will present a "dipole" field, which causes a signal like that shown in Figure 2. The relative size of the positive and negative lobes and their order of occurrence depends upon the direction which the sensor traverses past the object.

Another important variable is the distance from the sensor to the objects being detected. Objects of interest will probably be either proud on the bottom or buried a relatively small distance below the bottom, so a measurement of the altitude of the sensor above the bottom is required for detailed analysis. It is generally more difficult to measure altitude above the bottom, which requires an echo-sounding transducer, than depth, which can be accurately obtained from a pressure measurement. Though the sensor altitude can theoretically be calculated by subtracting the sensor depth from the water depth, measurements of water depth made from the ship do not necessarily apply to the location of the magnetometer behind the vessel. A precision depth sounder with recording capability could be used in conjunction with a precise navigation system to deduce the altitude of the sensor.

Once a method of determining the sensor altitude is established, some mechanism for maintaining a desired altitude throughout the survey must be established. This can be achieved by towing a controllable "depressor fin" in front of the sensor system. A reliable altimeter signal can be fed to the depressor control circuit to permit maintenance of the desired depth. It is also important to choose the altitude above the bottom to maximize the effective survey swath while maintaining sufficient sensitivity to detect desired objects. Based upon the following factors: the data in Figure 1; the desire to reliably detect all ordnance larger than 100 lbs (though most UXO found by SCI was smaller); and the need to maintain enough clearance to avoid snagging the magnetometer sensor on the bottom, SCI and EG&G Geometrics have determined that an altitude of about 5 m (15 ft) off the bottom provides the best compromise between sensitivity, survey speed and safety.

If the earth's field is constant or changing smoothly and relatively slowly, then the anomaly or signature caused by an iron object will stand out clearly from the record. Even an anomaly much smaller than the natural field fluctuations will be evident because its wavelength is much shorter than that of the natural variations. If the natural field fluctuates dramatically over short spans, however, then it can be extremely difficult to detect the anomalies caused by manmade iron masses. Detailed survey of suspect anomalies from single tracks will yield contour plots, analysis of which can confirm or lessen the probability of localized iron masses.

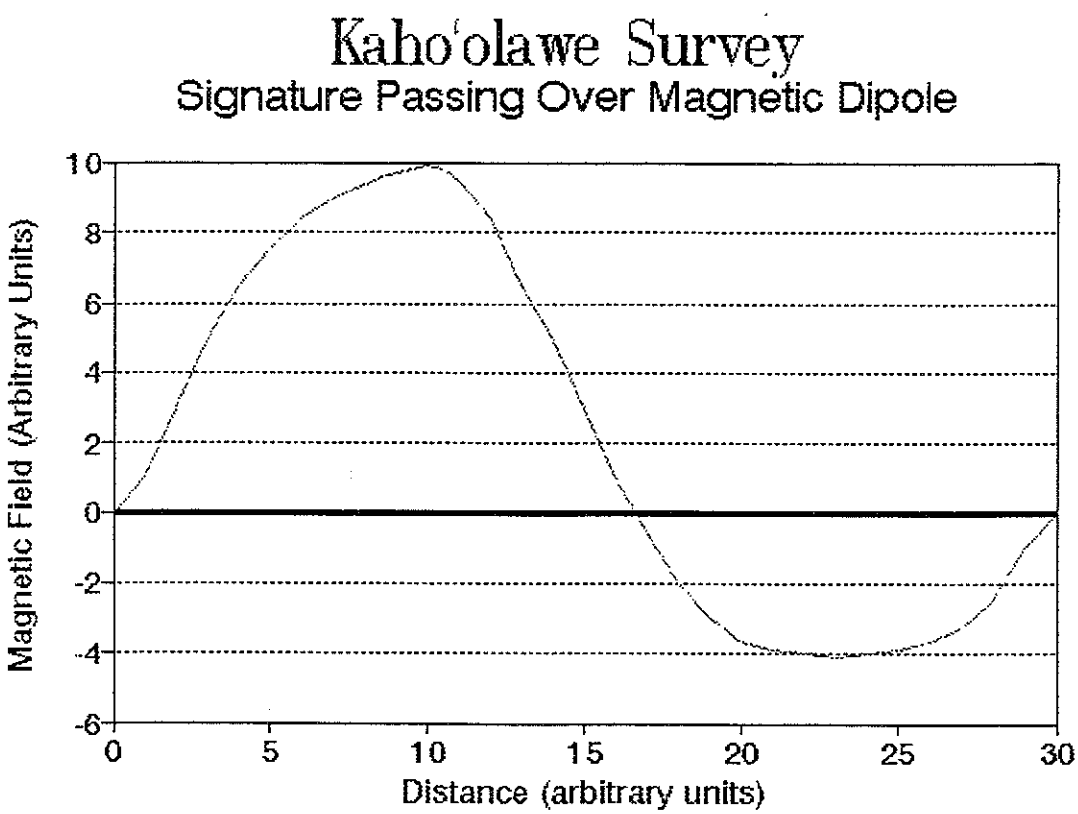


Figure 2. Plot of the typical magnetic field strength variation when the sensor passes a magnetic dipole. The distance scale is a function of the speed of the vessel as well as the sensor's distance from the object, while the magnetic field strength amplitude is a function of the mass of iron in the object, its degree of magnetization and its distance from the sensor.

In volcanic areas such as Hawaii, the natural lavas contain varying amounts of iron. Hawaiian lavas are generally deposited in thin (<10 m) layers, and flows are frequently narrow and confined to erosional depressions in the underlying lava. Repeated flows with differing iron content might thus produce an anomaly pattern of magnetic highs and lows with a spacing or wavelength about equal to the width of the flows, typically on the order of 10m. Some Hawaiian eruptions also produce high fountaining which can send ash and volcanic "bombs" over significant distances. Volcanic bombs can have significantly different iron content from the lava flows upon which they land, so they could produce a magnetic anomaly similar to that caused by a manmade iron object. Though there is no evidence that such volcanic bombs exist around Kaho'olawe, it must be remembered that they might be the cause of some measured anomalies.

4.2.7 Dolphin Object Location and Marking Systems

Dolphins use biosonar as one of their primary senses. They have evolved highly sophisticated biosonar which allows precise identification of objects and even determination of interior details of objects which are visually opaque. The dolphins produce clicks and process echoes over a wide range of frequencies, from the low attenuation long wavelengths to the high resolution short wavelengths. Their capability to quickly find and identify buried objects greatly exceeds any man-made system, under certain conditions. They can find objects in murky water, at depths that would severely limit bottom-time for human divers. They can perform underwater without the potential hazards of deep diving that humans incur.

Dolphin teams, consisting of several dolphins trained on various object discrimination tasks, have previously only been available to the US Navy. Recently this type of technology was declassified, and featured on a TV episode of "The New Explorers". The show was titled "Declassified: US Navy Dolphins" and produced by Bill Kurtis. The show featured another system providing an enhanced classification and survey capability, which allows operators on the surface to view an object, using a camera carried by the dolphin. The dolphins are trained primarily for man-made object location and could be used to find UXO on Kaho'olawe.

Dolphins, using their biosonar to echolocate objects hidden in mud or sand, can be trained to leave a small marking device on the bottom near the spot where the item was located. In actual practice, a diver will then be deployed to the marked site with a hand held magnetometer to classify the object reported by measuring the magnetic signal strength.

One challenge to the biosonar may be the presence of large numbers of boulders, large coral heads, or heavy coral encrustation of the targets, which can present acoustic shadows. These conditions present challenges to all known UXO detection systems. When marine mammal systems are used in these areas, they may mark coral heads of similar shape to UXO, forcing divers to confirm additional marks overall and slowing down the search rate.

In our experience, the dolphin object location and marking system is the detection system of choice for both exposed and buried UXO.

The Navy has been conducting marine mammal research and deploying marine mammal systems since the 1960's. The dolphin systems have a proven track record in detecting, locating, and marking a variety of manmade objects on and under the sea floor. Now this technology may be available to others through a Cooperative Research and Development Agreement or CRADA, a program to help explore new partnerships of private industry with military agencies. The CRADA sets out the relationship between the government agency and the private-industry contractor so that they can work together on mutually beneficial development efforts to further the application of dual-use technologies. The contractor receives technology that has not been available before, and in this case, valuable resources such as the dolphins that can be trained to accomplish the task.

4.3 Remediation Technologies

In this section we examine the remediation processes that will be required to make the waters surrounding Kaho'olawe reasonably safe for human use. We list and discuss methods of UXO remediation, and discuss the pros and cons of each method. As mentioned in section 5.3.2, the official permit for UXO clearance will determine which methods of remediation will be allowed. When removal is the appropriate remediation method, the disposal location and method will have a great impact on the removal methods and associated expenses.

Environmental conditions will also play a major role in determining remediation methods. Sea state, water depth, underwater visibility, current, wind speed, bottom composition, bottom profile, and the extent to which UXO might be "grown" into the bottom are some of the factors that will influence the decision process. One single method will not necessarily work in all conditions. More likely, a variety of approved methods will be available to the clearance team, which will then adapt the remediation program to the existing environmental conditions.

In this section we will establish priorities for our recommendations for remediation. We make two assumptions in developing the prioritization. The first assumption is that safety to humans, both clearance personnel and end users, is the primary concern. The second assumption is that whenever possible, UXO disposal by BIP should be avoided. The process of establishing priorities for the remediation techniques involved discussions with: experts in the field of UXO disposal, government agencies responsible for regulating environmental issues, members of the Protect Kaho'olawe Ohana, members of the Kaho'olawe Island Conveyance

Commission, academic researchers, and other concerned citizens. Finally, in this section, we present a remediation decision process.

The remediation techniques that we will examine are as follows:

(1) Removal
(2) Encapsulate and Remove
(3) Encapsulate and Leave
(4) No action
(5) Blowing in Place (BIP)

4.3.1 Removal

Removal of the ordnance is a common practice in UXO remediation projects on land. The EOD term for removal is "Pick Up and Carry Away" (PUCA). UXO should be removed from the shallow waters surrounding Kaho'olawe whenever removal can be accomplished safely. However, it is important to note at this point that while removal techniques are tried and tested on land, many known and some unknown conditions exist underwater that would preclude removal as a viable option.

We conducted interviews with 12 experts in the field of UXO disposal. All of the interviewees stated that removal should not be considered a safe option for underwater UXO disposal if it requires human contact with the UXO.

The U.S. Navy sets acceleration limits of 3g for hand carry and 10g for transport, based on tests conducted on unfired UXO. Lt. Greg Wheelock, Operations Officer at Explosive Ordnance Disposal Mobile Unit One, commenting on the tests, stated: "These tests were conducted on ordnance in pristine shape, under ideal conditions. Ordnance that has experienced long term exposure to salt water or the elements will be difficult to correctly identify, and may be embedded in coral growth or buried. Removing these ordnance items by hand would constitute a significant hazard. If it were my people in the same situation, we'd be blowing them where they sat." [19]

On land, UXO can be carefully examined to determine a relative degree of safety. In many cases of underwater UXO, the appearance of the UXO has been altered to the point where adequate inspection is not possible or environmental conditions are such that movement of the UXO would be unsafe. Some of the conditions that might make removal an unsafe method include:

1. UXO embedded in rock or coral to the degree that mechanical force would have to be applied to remove the UXO.
2. Shallow water in area of prevailing rough seas.

3. Sea water leaking into the munitions case may have sensitized the fuze/booster assembly.
4. Ambient water pressure may sensitize internal components that otherwise would not be hazardous at sea level.

Every phase of removal (lifting, transporting, dumping, etc.) increases the chances of detonation, and inadvertent detonation is a very real possibility. However, if underwater UXO can be adequately inspected and judged safe to move by a qualified EOD technician, then removal might be the choice for remediation. The ultimate determination of safety must be left with the disposal team.

There may be situations in which removal of UXO by remote methods can be safely and practically accomplished. Once again, the removal will be limited by environmental conditions. The methods may have to be modified on a case by case basis to suit the conditions. For example, a remote lifting system that can be used to remove UXO from a flat sandy area (Hana Kanaia) may not work in an area of boulders (Puu Koae). And since most of the UXO that is to be removed is buried, the exact lifting system cannot be determined until the UXO is uncovered.

There are remotely actuated lifting systems in existence that might work for removal of some of the UXO in Kaho'olawe waters. Using existing technology and/or specifically designed new systems, UXO might be removed by totally remote methods, precluding the need for divers. The degree to which remote systems are utilized will be determined by the relative degree of danger to humans. From our experience, systems that do not employ highly technical equipment and/or support are generally the most effective. This is particularly true when using systems in the ocean. With that in mind, systems should be developed that do not require a high level of maintenance and support. To the extent possible, the systems should be of generic designs in order to accommodate a wide range of ordnance.

The following three examples propose methods for remote removal of UXO and the equipment that might be required. In all three examples, the assumption is that a buried target has been detected in a flat sandy area. No assumption is made as to how the UXO is deemed safe or unsafe.

Example #1
The decision is made that it is safe to use divers to uncover the target. Once uncovered, the decision is made that it is safe for divers to rig a remotely actuated lifting system to the UXO. The lifting system consists of nylon slings that are wrapped around the UXO and attached to a remotely actuated float bag. The bag is inflated, raising the UXO off of the bottom, and the UXO is towed away for disposal elsewhere.

Example #2
The decision is made that it is safe to use divers to uncover the target. Once uncovered, the decision is made that it is not safe for divers to rig a lifting system and the rigging must be done remotely. A structure is lowered down which straddles the UXO. Hydraulically or mechanically actuated clamps then grab the UXO. A remotely actuated float raises the UXO off of the bottom, and the UXO is towed away for disposal elsewhere.

Example #3
The decision is made that it is not safe to use divers to uncover or lift the target. A structure is lowered down to the target area. A water jetting system incorporated into the structure is remotely actuated and sinks the structure into the sand while exposing the UXO. Once exposed, the UXO is rigged for lifting, lifted, and towed away for disposal elsewhere using the remotely actuated system described in example #2.

Remotely actuated systems should be designed to be as simple as possible. One existing remote lifting system incorporates a float bag that has SCUBA bottles attached to it. The SCUBA bottles are opened remotely. In our opinion, this is an overly complicated system. A simpler method would incorporate an air hose rigged to the bag and running back to a boat with an air compressor. The remotely actuated clamping system in examples 2 and 3 could be nothing more than spring loaded tongs that clamp around the UXO when the structure contacts the UXO. Of course, this assumes that sand clearance has been sufficient enough to allow closure of the tongs. This system would probably not work in rocky or coral areas. Such systems may already exist, but we are not aware of them and are not proposing that such be used. We present these examples only to show that totally remote removal might be possible.

"Remote operation" implies that humans are kept at a safe distance during the operation. The distance required for safety depends for the most part on the size of the UXO and the water depth. For example, the safe distance for remotely removing a 500 pound bomb in 30 feet of water is greater than the safe distance required for remotely removing a smaller bomb in deeper water. We recommend that the remediation team follow procedures outlined in the Draft Dennison report of 3 Oct 1992 to determine safe distance [6].

When lifting UXO from the bottom for disposal in deep water (if the permit allows that), care should be taken to lift the UXO only enough to clear bottom obstructions enroute to the disposal sites. The reason for this precaution is to avoid exposing the UXO to excessive pressure reductions. To accomplish this, the float bag should be rigged on a pendant of sufficient length to place the deflated bag just below the surface of the water. When inflated, the bag and the UXO will ascend only a few feet, minimizing the pressure reduction and thus the chances of inadvertent detonation. In addition, UXO containing white phosphorous should not be brought to the surface, as exposure to air could ignite the white phosphorous.

Remotely Operated Vehicles (ROV) are commonly used to perform work underwater. ROV's are specifically designed for particular tasks, and existing ROV's might work for UXO location and removal. However, the effectiveness of ROV's to locate and remove UXO from the waters surrounding Kaho'olawe will be limited by:

1. The ability to function in high surge areas.
2. The ability to function in confined areas. Underwater UXO tends to migrate to depressions in the bottom or become lodged in crevices.
3. The ability of the ROV to remove coral encrusted UXO. The ROV might have to anchor itself to the UXO or to the bottom in order to perform work.
4. The ability of the ROV to handle irregular shapes. Marine growth creates irregular shaped UXO.
5. The capabilities and limitations of the support vessel.
6. The abilities of the ROV operator.

To summarize our opinion of removal as a method of remediation: remote systems should be employed whenever practical, and divers should only be involved with removal operations if there is absolute assurance that the UXO is safe to move.

4.3.2 Encapsulation

We will discuss encapsulate and leave, and encapsulate and remove techniques together because they are basically similar procedures. As previously mentioned, removal of UXO will have to be considered on a case by case basis. There may be situations that make removal desirable but unsafe unless the UXO is first encapsulated in concrete. We place this method second on the removal prioritization because it still accomplishes the goal of removal without detonation in place and in our opinion adds a margin of safety to the removal operation.

If the encapsulated UXO cannot be removed, the next best option in the order of priority, is to leave the encapsulated UXO in place. Encapsulation, to a certain degree, denies access to the UXO by providing a physical barrier to swimmers or divers who might otherwise attempt to remove or tamper with the UXO. It also provides physical protection from small boat anchors. However, encapsulation will not render the UXO safe. Unless removed, it will remain a hazard, and will possibly hamper future UXO monitoring surveys.

If done properly, encapsulating UXO in concrete might make it less of an environmental hazard. If this were found to be the case, ocean dumping of the encapsulated UXO might be a viable consideration in the permit process.

Encapsulating a piece of UXO in concrete for later removal will probably be limited to fairly flat areas of sand, silt, or hard bottom. If removal after encapsulation is not required, UXO in areas of coral, rocks and rubble can be encapsulated.

Concrete can be poured underwater and will set up underwater. Proper formulation and installation of the concrete mixture is essential for underwater strength and durability. Concrete should be premixed and pumped into a form on the bottom by means of a tremie pipe.

The ideal situation would involve a concrete batch plant on a floating platform supplying mixed concrete to a concrete pump that sends the concrete to the bottom through a tremie pipe or hose. Concrete is composed of cement, fine aggregate (sand), course aggregate (rock), and water. If it is not pumped through a tremie pipe and the concrete is exposed to seawater, the light particles of cement tend to wash out of the concrete with potential for serious particulate pollution and leaving the heavier but weakened aggregate.

The ideal underwater form is fully enclosed and has two ports, one for supply of tremie concrete and the other for exhaust of seawater that is displaced by incoming concrete. Concrete is pumped into the form until all of the water within the form has been displaced. This method has the added advantage of limiting the deposition of undesirable sedimentation ("laitance") in the surrounding area. Forms are generally made of metal, wood, or concrete. Zippered fabric (nylon, polyester) bags are manufactured for special applications such as piling repair. It is unlikely that zippered fabric bags could be adapted because, to work properly, the bag would have to surround the UXO. Metal and wood forms would need to be modified for each piece of UXO due to uneven bottom contours. Also, metal and wood forms might require removal after the concrete has set. Precast concrete forms can be made from scrap material (sections of pipe) and do not require removal, as the precast form becomes part of the encapsulation structure. The precast concrete forms would require field modifications for uneven bottom contours, but this could be done with sand bags. Rough seas or shallow water might limit the use of lifting equipment and support craft required for pumping concrete, in which case a more likely approach would involve using sand filled bags as a perimeter form around the UXO.

The SCI underwater survey revealed that wave action and currents tend to move UXO towards depressions in the bottom. This fact makes forming easier, as the natural depression, augmented with sand filled bags, could be used as the form for the concrete pour. Sand bags are easily installed by a diver working out of a small boat. A disadvantage to this method is that because the form is not fully enclosed, some laitance will be deposited in the surrounding area. Mr. John Naughton of the National Marine Fisheries office in Honolulu stated [20], that from his experience, the laitance that would settle on surrounding bottom formations, while undesirable, would be acceptable when compared to the damage to the surrounding area that would result from blowing the UXO in place.

On May 23, 1987 the U.S. Navy encapsulated a 1000 lb. bomb in 30 feet of water within Molokini Shoals Marine Life Conservation District [21]. The decision to encapsulate the bomb was made because of public sentiment that blowing the bomb in place would damage the reef within Molokini crater.

Encapsulating buried UXO could frequently be accomplished by first exposing the UXO with an airlift or other dredging method, and then using the depression created by the dredging operation as the form for the encapsulation.

Curing concrete produces an exothermic reaction, meaning that the curing process generates heat. We have not been able to determine if sufficient heat might be generated for potential detonation. Our opinion is that, because the concrete is curing underwater, the change in temperature will be insignificant. More research should be done, however, to answer that question.

To facilitate later removal of encapsulated UXO, a simple reinforced steel cage incorporating a lifting eye could be set around the UXO and cast into the concrete pour. After the concrete has cured, a float bag could be attached to the lifting eye, the bag inflated, and then the UXO could be towed to an area for disposal. This method might not work if the UXO has grown into the bottom, since too much force might be required to break the encapsulated UXO free of the bottom. It is possible that this entire procedure could be accomplished remotely, but probably with very limited success.

4.3.3 No Action

There may be times when leaving UXO alone will be the safest and most environmentally sound approach. While doing nothing cannot be considered remediation, we feel that it is appropriate to discuss it as a possible option.

There are areas around the coast of Kaho'olawe that are inaccessible except by boat. On the south shore of the island, in many spots, the 120 foot curve is very close to the base of the sea cliffs. Anchoring in the areas of very steep underwater cliffs is difficult and unlikely. While it is doubtful that people will approach these areas from land, and anchoring is difficult, there is still a danger to divers and fishermen.

There may be secret fishing spots or underwater archaeological sites that the remediation team is not aware of. The KICC report [1] refers to fishing shrines that were used as land marks to locate fishing spots. These fishing spots are considered secret by the Hawaiians. If UXO is found in such a site, the appropriate parties should have the opportunity to protect the sites. If the only safe method of remediation is BIP, then the decision might be made to leave the UXO. If UXO is found in an area of extensive coral, and BIP is the only safe method of remediation, then the decision might be made to leave the UXO. This situation will have to be dealt with on a case by case basis, utilizing input from concerned parties. For the most part, the decision to leave UXO in place will be determined by safety considerations, environmental impact assessments, and the intended future uses of the area.

4.3.4 Blow in Place (BIP)

We are of the opinion, that in most cases, BIP is an undesirable and perhaps environmentally unsound approach to underwater UXO remediation. BIP should only be used if, in the opinion of all concerned, no other option is feasible.

There will very likely be situations in which BIP is the only safe method of disposal. It is important to reemphasize at this point that all of the U.S. Navy EOD Technicians interviewed stated that removal should not be considered a safe option for underwater UXO disposal if it requires human contact with the UXO. BIP is the method of choice of the U.S. Navy.

An example of a situation that could dictate BIP would be UXO very close to shore, lodged into a crevice of a near vertical underwater cliff. The Southeast and South shores of Kaho'olawe have steep underwater cliffs and very rough prevailing wind and sea conditions. In the example, removal would not be practical because the UXO would have to be pried out of the crevice. Encapsulation would not be practical because of the near vertical cliff. Rough sea and wind conditions would exacerbate the problem.

Should the decision be made to BIP, there are several factors to consider. One consideration is how much High Explosive (HE) will be required to achieve total destruction of the UXO. The amount of HE must not be of such amount to cause unwarranted and excessive damage to the surrounding underwater flora and fauna. By careful analysis and subsequent identification, an experienced EOD technician will be able to determine whether the UXO is composed of a thick or thin case. The amount of HE required to achieve total destruction differs drastically between thick and thin case munitions. A 100 pound Flash Bomb may only require a 1 1/4 pound block of HE to detonate it, but a 500 pound GP Bomb may require 20+ pounds of HE to achieve total destruction. In any case, the detonation charge is only a small percentage of the HE in the UXO.

The usual recommended method utilizes an electric firing train rather than non-electric initiation. Electric firing offers the EOD team almost total control over the moment of detonation. A nonelectric initiation requires the EOD team to enter the explosive hazard zone and sever the firing train if an unsafe condition occurs. Approaching a burning explosive train puts the EOD team at unnecessary risk by totally relying upon the calculated burning time of the time fuze. Time fuze doesn't always burn at its prescribed rate, and subjecting it to seawater adds another degree of uncertainty.

The primary concern with BIP is the potential for environmental damage. The Naval Surface Warfare Center published a report in July 1992, [22] which addressed the environmental impact to marine flora and fauna during underwater explosives testing and referenced two other reports. Two graphs taken from that report indicate safe distances for marine fauna during underwater explosions (See Appendix D). This report might be used as a reference during the remediation decision process.

We present the following case history as an example of a remediation decision process used in the past.

In 1990, a piece of UXO was found in 12 feet of water 25 yards off Kukui Point on Kaho'olawe. The UXO was a rocket with 152.5 pounds of HE. The U.S. Navy proposed to dispose of the UXO by BIP, but first wrote to the Honolulu office of the National Marine Fisheries service for a response to the proposal. Mr. John Naughton, Pacific Islands Environmental Coordinator, National Marine Fisheries Service responded by letter on October 5, 1990 [23]. In part, he states:

> "NMFS in general recommends against detonation in place. We feel alternatives such as physical removal, slinging and jettisoning in deep water, and encasement in place with a concrete cap should be given full consideration".

Later in the letter, Mr. Naughton states:

> "NMFS has discussed the subject piece of ordnance with your Civil Engineer office and with Explosive Ordnance Disposal (EOD) Unit Personnel who surveyed the site. These discussions revealed that the rocket may be particularly dangerous and any movement may cause it to detonate. It is also located in an underwater canyon with coral ridges closely approaching the surface. This should serve to minimize lateral impact from detonation in place. In view of the above, and providing the alternative of concrete encasement is considered, NMFS will not object to the proposed demolition action at this time. However, we recommend the following conditions be incorporated into the project:
>
> 1. A vessel and diver survey shall be conducted prior to detonation to detect the presence of any large marine animals (rays, sea turtles, marine mammals) or

schooling fish. Detonation shall be delayed until such animals have departed a 100 yard radius safety zone surrounding the ordnance.

2. At least one week prior to detonation the Navy shall notify the Hawaii State Division of Aquatic Resources (DAR) and NMFS. Observers from DAR and NMFS should be allowed to participate in pre and post detonation site surveys.

3. Should demolition be delayed beyond November the project shall be postponed until at least the following May to assure the humpback whale population has departed the nearshore waters of Hawaii."

On July 14, 1993, Mr. Naughton stated in a letter [20] that the conditions listed above would be appropriate for future underwater UXO clearance on Kaho'olawe.

In condition number 1, Mr. Naughton recommends that a vessel and diver survey be conducted prior to detonation to detect the presence of any large marine animals or schooling fish. We consider this to be an essential procedure but one that will be difficult to accomplish with any reasonable degree of confidence.

During each day of our survey, a relatively large pod of spinner porpoises (Stenella longirostris) swam in the waters offshore Smugglers Cove. The DLNR, [3] reported two pods of spinner porpoises. While marine mammals are easily identified from a vessel, we can think of no legal way to insure that marine mammals are clear of the blast area. Further research might reveal possible acoustic signals which would keep them away, but this is only speculative.

Schooling fish present a very difficult problem. In areas of good underwater visibility, a team of divers might be able to adequately survey the area prior to blasting. However, in areas of poor underwater visibility such as Ahupu and Kuheia, divers would be ineffective. It is conceivable that a boat equipped with a "Fish Finder" sonar could locate and then chase schools of fish from the blast area.

To summarize our opinion on BIP as a method of UXO remediation, we feel that it should be considered only as a last resort after all other options have been considered.

5.0 POTENTIAL CLEARANCE PLAN

5.1 Planning Assumptions and Limitations

In order to produce a plan which allows a preliminary cost estimate and schedule to be developed, assumptions must be made about several variables which impact the planning process. These assumptions include: future intended use of the island waters, technologies selected for detection and remediation, and risk assessment criteria.

It should be noted that these assumptions do not constitute formal recommendations. The scope and funding of this study was not sufficient to provide for such recommendations. Therefore the assumptions that follow are for planning purposes only.

5.1.1 Water Use

For purposes of planning what level of clearance operations is required, it is important to know what sorts of activities are anticipated in the waters to a depth of 120 feet. The specific cultural activities are still being researched, but we know they will involve the launching and mooring of boats from beaches and protected coves as well as fishing and diving offshore. We also know that large boats, barges, small piers and floating causeways will be required to conduct all the UXO clearance operations on land and at sea.

The DLNR Historic Preservation Division may be interested in conducting marine archaeology research in sites that they know of or other sites that UXO search teams may find. In addition, there will be many types of before-and-after bio-assays conducted by DLNR Aquatic Resources, NOAA, NMFS, & HIMB to assess the environmental costs of UXO clearance operations.

5.1.2 Detection and Remediation Assumptions

For purposes of developing a clearance plan and estimating the cost of the clearance, we make the following assumptions:

1. Marine mammals systems will be the primary detection method for both buried and unburied UXO.
2. Divers and towed video will be used as a secondary detection method for unburied UXO.
3. Advanced technology (such as hand held or towed magnetometers or another yet to be determined technology) will be used as a secondary detection method for buried UXO.

4. Removal will be the method of choice for remediation when it can be accomplished safely.
5. Blowing in Place (BIP) is the least desirable method of UXO removal.

5.1.3 Risk Assessment Assumptions

To our knowledge, there are no risk assessment standards available for these types of activities. The Army Corps of Engineers is responsible for regulating UXO clearance work, but to our knowledge no UXO clearance operations work of this scope has ever been undertaken underwater, and no established clearance standards exist. That leaves us to apply sound principles of EOD remediation training in the best possible way to each case on an individual basis.

5.2 Clearance Categories

We propose three clearance categories:

Category 1 (Cat 1) - survey and clear exposed UXO from the sea floor bottom from all nearshore waters, out to a depth of 120 feet.

Category 2 (Cat 2) - complete survey and clear UXO from the sea floor to a depth of 18 inches below the bottom.

Category 3 (Cat 3) - survey and clear UXO from the sea floor in specified large support craft anchorages to a depth of 6 feet below the bottom.

Note: These clearance categories are designated on maps 1-9 in the Map Section.

5.3 Project Coordination

We recommend that the on-island representative of the Oversight Commission convene weekly meetings of representatives from each activity present on the island. The purpose of the meetings will be to coordinate plans between the different groups. While the underwater clearance will for the most part be operationally independent of the other groups, there situations will arise that affect all groups. This will be especially true if housing, eating, transportation, communication, and other facilities are shared as we recommend.

In section 5.4.3 we will discuss the Remediation Decision Flowchart. The purpose of the flowchart is to insure that appropriate parties are given the opportunity to evaluate the remediation process as the operation progresses.

5.3.1 Quality Assurance Program

The Quality Assurance Program will be administered by the Quality Assurance Supervisor, who will report directly to the Site Superintendent. The QA Supervisor will be a qualified EOD Technician and will be assisted by another EOD Technician.

We are not aware of any published QA Standard for underwater UXO remediation, but we recommend that the program follow a zero failure criterion. The QA Supervisor and QA Assistant should be qualified divers so that they can make periodic inspection dives. Inspecting underwater work is more difficult than inspecting work on land. The inspector cannot always see what is taking place. Therefore, for the underwater operation, the QA program will depend on very accurate tracking of the operation via the Geographic Information System.

5.3.2 Plans, Permits, and Procedures Development

Thorough planning will go a long way towards insuring a successful clearance operation. The Operations Plan for the underwater clearance will be very involved and should be completed prior to mobilization. Planning for the underwater operation must incorporate substantial contingency plans, primarily to deal with weather days. The winter months will be especially difficult to plan. We anticipate that during roughly 20% of the year, weather conditions will prohibit underwater work. The plan should have weather days allocated as well as equipment maintenance, professional training, unscheduled vacation, etc.

The Operations Plan should be of sufficient detail to keep the detection team employed full time and ahead of the remediation team. The Operations Plan must have a detailed Emergency Procedures/Accident Prevention section that clearly defines areas of responsibility, training requirements, hazard communication, etc. Of particular importance to the Emergency Procedures section will be the Emergency Dive Bill.

Depending on the contracting authority, all diving operations will most likely be governed by either OSHA (29 CFR 1910, Subpart T--Commercial Diving Operations) or by the U.S. Army Corps of Engineers Safety and Health Requirements Manual (EM 385-1-1 1 OCT 92). Both of these publications clearly define the training, operations and reporting requirements and procedures for commercial diving.

To the best of our knowledge, no decision has been made about which government agency will administer the job of underwater UXO remediation. In the past, UXO remediation jobs have been administered by the U.S. Army Corps of Engineers, and we assume that will be the case.

We interviewed officials from the Corps of Engineers, the Environmental Protection Agency, the National Oceanic and Atmospheric Administration, the State of Hawaii Department of Land and Natural Resources, and the Naval Surface Warfare Center Ordnance Environmental Support Office.

A complete Department of the Army Permit Application consists of the application form (Eng Form 4345), drawings, and environmental information. The Corps of Engineers advises that necessary environmental information is often lacking when the application is submitted, which results in delays in processing the permit application. The Corps of Engineers has developed a questionnaire to simplify the submittal of environmental assessment information.

According to the officials that we interviewed, the permit process could take from 6 months to 3 years, depending on what environmental tests are required. The cost of obtaining the permit could exceed $1,000,000 if extensive bottom samples testing is required. Bottom sampling tests will be required if dredging is included in the remediation process. In our opinion, the permit process should be started as soon as possible.

5.3.3 Staff Training Programs

Training requirements for divers are clearly defined in the OSHA Manual (29 CFR 1910m Subpart T). These requirements include initial training certification, medical history and record keeping, and reporting procedures. All divers for this operation should be graduates of either a military or commercial dive school. EOD divers should be U.S. Navy trained.

An initial training program should be established to standardize detection and remediation procedures. Refresher training should be conducted on a regularly scheduled basis and should be augmented by additional training on weather days. The training should include detection methods, equipment operations and maintenance, annual CPR refresher training as required by OSHA, tri-annual First Aid refresher training as required by OSHA, emergency procedures, and recompression chamber operations. Individuals should be required to pass both a written and practical exam prior to participating in UXO detection and/or remediation.

5.4 Clearance Plan

In this section we recommend a plan to clear UXO from the waters of Kaho'olawe out to a depth of 120 feet deep. The objective of the clearance operation is to make the waters reasonably safe for human use. Human uses of the waters will include swimming, skin/scuba diving, spear fishing, various other forms of fishing (bottom, trolling, throw net, lay net, shore casting, etc.) opihi picking, limu picking, various forms of boating, and others. Since we don't consider total clearance of UXO from the waters to be possible, the waters may never be totally safe from UXO accidents.

The clearance plan involves detection and remediation of UXO. As noted above (p. 4 - 4), an initial magnetometer survey will locate areas of potential UXO concentration. Then detection and remediation will be conducted in successive clearance areas around the island. Detection teams will include video systems, divers and marine mammals.

We propose that two clearance options be considered:

Option A

1. Clearance of all exposed UXO from the waters surrounding Kaho'olawe from shore out to 120 feet deep.

2. Clearance of all buried (18" deep) UXO from the waters surrounding Kaho'olawe from shore out to 120 feet deep.

3. Clearance of all buried (6' deep) UXO from shore out to 120 feet deep in designated deep draft anchorages (Cat 3 Heavy Mooring Areas, Hana Kanaia, Kuheia, and Hakioawa).

Option B (Represented on Maps in MAP Section)

1. Clearance of all exposed UXO from the waters surrounding Kaho'olawe from shore out to 120 feet deep.

2. Clearance of all buried (18" deep) UXO from shore out to 120 feet deep in Special Development Areas (SDA's: Hana Kanaia, Honokoa, Ahupu, Kuheia, Kaulana, Hakioawa, Kanapou, Kamahio) Note: the Kuheia SDA has been extended to the bay to the south which is a good anchorage during prevailing winds. Other SDA Coundary adjustments were made at Kanapou and Kamohio to provide for a proper anchorage.

3. Clearance of all buried (6' deep) UXO from shore out to 120 feet deep in designated deep draft anchorages (Cat 3 Heavy Mooring Areas, Hana Kanaia, Kuheia, and Hakioawa).

5.4.1 Infrastructure Development

5.4.1.1 General Infrastructure

In all probability, the clearance of UXO from the land portions of Kaho'olawe will require substantial upgrading of the existing infrastructure. The Ballena Systems Corporation report [24] recommended that, among other structures, a dock be installed at Hana Kanaia to facilitate loading and off loading. Any construction in Hana Kananaia would require prior UXO clearance in the land and underwater areas of the construction.

For cost estimating purposes, we have structured the underwater clearance operation to be autonomous and independent of the land clearance operation. However, we are of the opinion that a more efficient approach would be to combine the efforts by sharing resources and infrastructure. Both land and underwater operations will require communication and navigation systems. If properly planned, the systems could be shared. The same is true for maintenance, housing, food, medical, transportation, and other components. The underwater operation will require a dedicated dive locker, including a recompression chamber and compressors. The pier design will require specific input from marine mammal experts regarding design parameters for the use of marine mammals. Marine mammals will also require a fish preparation facility and dedicated freezer space.

The underwater clearance operation can get underway with relatively short lead time, assuming that existing infrastructure will be available to the clearance team. The initial magnetometer survey, which will provide input data for determining areas of detailed search, detection and remediation activities, can be conducted from a ship with minimal shore support other than navigation systems. As noted above (p. 4 - 4), this survey will require significant data reduction follow-up to provide the desired information, so it could well precede other activities by a significant period of time. The underwater clearance activities can be phased in to accommodate the construction at Hana Kanaia.

5.4.1.2 Mooring Buoy System

One of the first infrastructure components which might be installed on the Kaho'olawe work site would be the beginnings of a Mooring Buoy Anchorage System. This is logical because conventional anchoring on Kaho'olawe presents a number of disadvantages. Small vessels in deep water and large vessels in all waters require a great deal of anchor rode to anchor safely. When multiple vessels anchor in the same area, they risk bumping into each other or running aground at night under variable wind conditions. Another problem with conventional anchors and anchor chains is that they drag along the bottom causing extensive damage to marine life and archeological features. On Kaho'olawe, they run the risk of striking and possibly detonating UXO that escaped detection during clearance operations.

A mooring buoy system has a number of advantages over anchoring by conventional means. The foremost is eliminating the potential of dragging anchors striking UXO. It also provides good moorings for a greater number of vessels in a limited area. Finally, it causes less environmental damage than conventional anchoring. By installing mooring buoys at the outset, these risks can be minimized when the danger from UXO is greatest.

Such a system has potential long term benefit for the The Kaho'olawe Island Reserve Commission in that it will provide a means to control access to Kaho'olawe waters. A similar situation exists in the Santa Cruz Island Nature Conservancy in California, which requires special permission to moor boats at designated moorings in the nearshore waters. The reservation process can be adjusted according to the K.I.R.C.'s need to address cultural or environmental concerns. Mooring fees may be charged to assure the long term maintenance of the program.

5.4.2 Clearance Order

Job 1 - All areas will be required to be cleared to Cat 1 levels before beginning Cat 2 and Cat 3 clearance. Assume Cat 1 clearance to precede Cat 2 and Cat 3 clearance on all of the following jobs.

Job 2 - We recommend that the 39 acres of Cat 3 clearance at Hana Kanaia SDA be planned as the first job in the underwater clearance operation. The marine equipment that will be required to construct the dock facilities will need an anchorage area. Clearance depths for the immediate area of the dock will be dictated by design. If the design includes driven pilings, site specific clearance will be required.

Job 3 - The Cat 3 clearance at Kuheia SDA should follow the Hana Kanaia clearance. Kuheia affords an alternate anchorage for transporting equipment for the land clearance operation.

Once Hana Kanaia SDA and Kuheia SDA Cat 3 clearances are complete, the land clearance teams will have better access to the island, and the balance of the underwater clearance can commence as follows:

Job #	Description
4	Cat 3 clearance at Hakioawa SDA
5	Cat 2 clearance for balance of Hakioawa SDA
6	Cat 2 clearance for Honokoa SDA

7	Cat 2 clearance for balance of Hana Kanaia SDA
8	Cat 2 clearance for balance of Kuheia, Kuheia extension, and Kaulana SDA's
9	Cat 2 clearance for Kanapou SDA
10	Cat 2 clearance for Ahupu
11	Cat 2 clearance for Kamohio SDA

5.4.3 Remediation Decision-Making Process

The objective of the remediation program will be to make the waters surrounding Kaho'olawe reasonably safe for human use, while minimizing environmental damage. As stated earlier, we make two assumptions in developing the remediation prioritization. The first assumption is that safety to humans (clearance personnel and end users) is the primary concern. The second assumption is that whenever possible, UXO disposal by blowing in place should be avoided.

The ultimate determination of safety must be left with the disposal team. If the disposal team determines that a particular piece of UXO must be blown in place or left alone, then we recommend that steps be taken to notify concerned parties. The goal will be to give the appropriate authorities an opportunity to evaluate the situation, while minimizing delays in the remediation effort.

The flowchart (Figure 3) demonstrates how the notification process might function. If for example, the remediation team determines that the UXO cannot be removed or encapsulated safely, then the UXO would be documented (type, location, depth, photo, video, general condition, etc.) and the Oversight Commission would be informed. The Oversight Commission would in turn notify the appropriate concerned parties (NMFS, DLNR/DAR, PKO, etc.) as appropriate. The concerned parties would have two weeks to evaluate the situation as required and respond to the Oversight Commission. The Oversight Commission would make the final decision and notify the remediation team whether to blow the UXO in place or leave it alone. Table 6 lists the pros and cons that they would weigh in making their decision. There may be additional concerned parties that should be involved in the notification process. The Oversight Commission should determine who is notified.

5.4.4 Long Term Clearance Plan

Clearance of UXO that may be uncovered during large storms or washed into the ocean from land, should be considered. We suggest development of a plan for an annual surface survey of 10% of the island waters to 120' plus areas where there have been reports of UXO sightings. These surveys should completely canvas the waters to 120' every ten years.

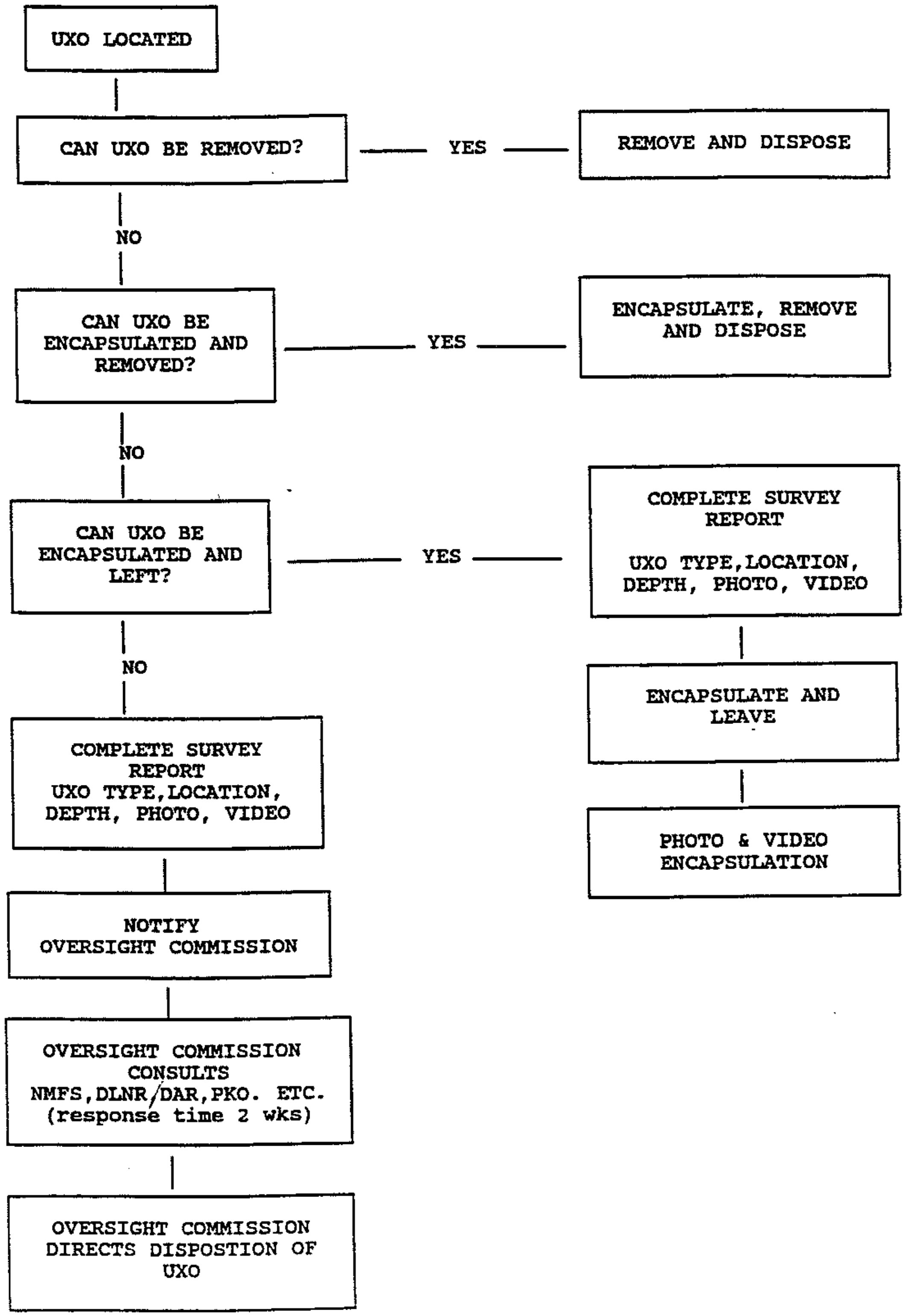


Figure 3

Remediation Decision-Making Flowchart

Table 6

REMEDIATION METHODS PROS AND CONS

Method	Pros	Cons
Removal	1. Removes UXO from site 2. Possible low environmental impact 3. Preferred method of NMFS, DLNR/DAR	1. Greater danger 2. High Cost 3. Requires transport for disposal 4. Every extra phase of handling increases risk
Encapsulate/Remove	1. Removes UXO from site 2. Possibly safer than removal 3. Might improves chance of getting permit to dump at sea	1. High Cost 2. Requires transport for disposal 3. Every extra phase of handling increases risk
Encapsulate/Leave	1. Provides physical barrier to humans 2. Low environmental impact 3. Most preferred by NMFS if removal not possible	1. UXO remains in place 2. Possibly complicates future monitoring 3. Inadvertent detonation still possible
Blow in Place (BIP)	1. Removes UXO from site 2. Low Cost 3. Relatively safe when done by qualified EOD technicians 4. Preferred by US Navy EOD	1. High environmental impact 2. Limited to May through October
No Action	1. Relatively low cost 2. Low short term environmental impact	1. UXO remains in place 2. Area will be off limits 3. Future on-going monitoring raises long term cost 4. Unknown long term environmental impact

5.5 Clearance Team Composition

We have divided the underwater UXO clearance team into a detection group, a remediation group, an administrative group, and a support group. The goal will be to have a schedule that allows the team to operate year round. But the underwater clearance operation will have scheduling limitations that the land clearance operation will not have to contend with. During the months of November through April, no underwater detonations will be allowed. Also, wind and sea conditions will to some extent dictate where and when underwater detection and remediation can occur.

The resident team proposed consists of 71 individuals, whose labor categories are listed in Table 7. We determined salary costs by using the current prevailing wage from the State of Hawaii Department of Labor and Industrial Relations Wage Rate Bulletin. For labor categories not listed in the Wage Rate Bulletin, we estimated what we consider to be reasonable prevailing wages. We consulted with the U.S. Army Corps of Engineers office in Honolulu, the U.S. Department of Labor in Honolulu, and the State of Hawaii Department of Labor and Industrial Relations. We were advised that while the State of Hawaii Department of Labor and Industrial Wages Rate Bulletin might not be the appropriate wage determination, it would be a good source for estimating wages.

Figure 4 shows the organization of the team. The project Manager would be in overall charge of the operation. The KIRC Liaison's function will be to facilitate communication between the commission and the clearance team. The Off-Island Manager will assist the Project Manager as necessary. The Site Superintendent will be EOD Qualified and will have responsibility for the day to day operations on the island, with authority over the Detection, Remediation, Support, Administration, Quality Assurance, and Health/Safety/Training Managers.

5.6 Cost Estimate

Cost estimates have been developed for both Clearance Option A and Clearance Option B. Table 8 gives the estimated clearance rates for all clearance categories for both Option A and Option B. These rates take into account lost operational time due to weather, daily pre-clearance and post-clearance activities, clearance related support activities and unexpected interruptions. These clearance rates at this point constitute the critical path for scheduling of this project.

The same staffing model (Table 7) was used for both estimates; only the duration of clearance activities was changed to account for the different levels of activity. The gross hourly wage shown in this table for the 71 person team is $2072. Table 9 shows estimates for the Year 1 Labor Cost. Taking the gross hourly wage we added a 5% inflation multiplier assuming that hourly wage rates will increase

Table 6

UXO Clearance Team Staffing Model

A Item Number	B Number of Staff	C Labor Category	D Information Source*	E Hourly Wage	G Total Cost/Hour
1	4	Bio Technician	2	$43.25	$173.00
2	1	Bio Technician Consultant	2	$43.25	$43.25
3	1	Bio Technician Manager	2	$40.00	$40.00
4	3	Bio Technician/Diver	1	$43.25	$129.75
5	1	Boat Engineer	1	$21.53	$21.53
6	5	Boat Operator	1	$21.53	$107.65
7	3	Branch manager	2	$35.00	$105.00
8	1	Budget Manager	2	$25.00	$25.00
9	1	Civil Engineer	2	$25.00	$25.00
10	1	Contract Adminstrator	2	$22.50	$22.50
11	2	Cook	2	$14.00	$28.00
12	1	Custodian	2	$12.00	$12.00
13	1	Data Analyst	2	$22.50	$22.50
14	4	Deckhand	1	$19.47	$77.88
15	3	Dive Supervisor	1	$43.25	$129.75
16	9	Diver	1	$43.25	$389.25
17	2	Diving Medical Technician	1	$43.25	$86.50
18	3	Electronics Technician	1	$24.62	$73.86
19	1	Emergency Medical Technician	2	$20.00	$20.00
20	1	Equipment Operator	1	$19.19	$19.19
21	3	Equipment Specialist	2	$20.00	$60.00
22	1	GIS Specialist	2	$22.50	$22.50
23	1	Health/Safety/Training Officer	2	$25.00	$25.00
24	1	KIRC Liaison	2	$30.00	$30.00
25	3	Laborer	1	$16.65	$49.95
26	3	Mechanic	1	$21.53	$64.59
27	3	Nav/Comm Technicians	2	$22.50	$67.50
28	1	Off-Island Manager	2	$35.00	$35.00
29	1	Office Manager	2	$25.00	$25.00
30	1	Project Manager	2	$50.00	$50.00
31	1	Q/A Assistant	2	$18.00	$18.00
32	1	Q/A Manager	2	$25.00	$25.00
33	2	Secretary	2	$15.00	$30.00
34	1	Security	2	$18.00	$18.00
	71			$926.02	$2,072.15

* Information sources on wages are the following
  (1) Current State of Hawaii published wage rates
  (2) Estimated prevailing wage rate

FIGURE 4
Underwater UXO Clearance - Organization Chart

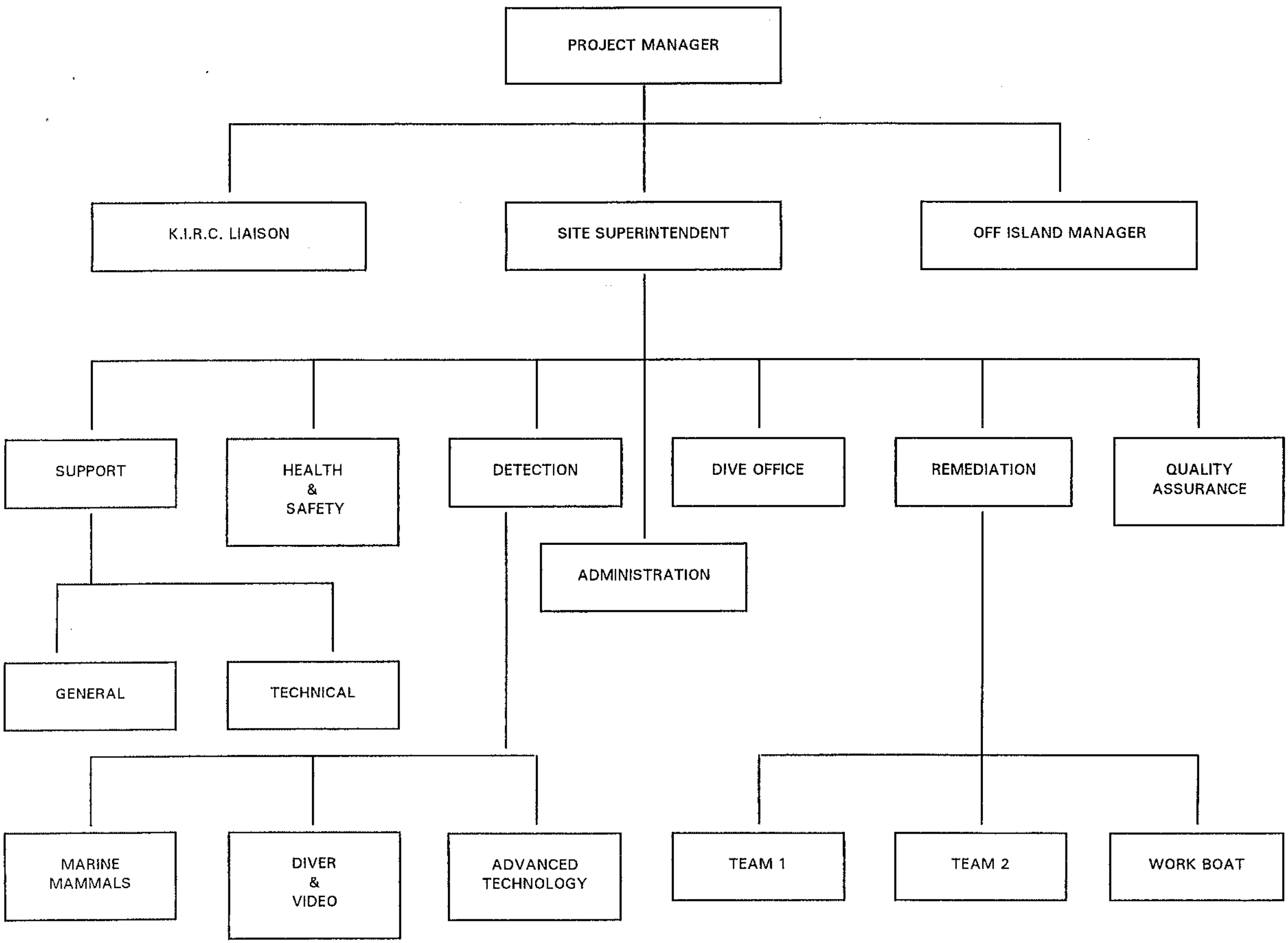


TABLE 8

UXO Clearance Rates by Clearance Category

Clearance Category	Acres Cleared Per Day
Category 1	8
Category 2	2
Category 3	0.5

TABLE 9

Year 1 Labor Cost Estimate

Current Base Hourly Wage Rate	$2,072
Adjust for 1 year delay	5%
Overhead/ Burden Multiplier	2.5
Fully Burdened Hourly Wage Rate	$5,439
Total Labor Cost	$11,313,939

by this amount by the time the project actually begins operations. We then assumed an industry average burden of 2.5 times the gross hourly wage rate to yield a fully burdened hourly wage rate of $5,439. The annual labor cost was then obtained by multiplying the fully burdened hourly wage rate by 2080 working hours per year. This yielded an annual labor cost of $11,313,939 for the first year of operation.

We are assuming that existing infrastructure will be available and will be adequate only for the initial phase of clearance in Hana Kanaia. We did not include costs for infrastructure development as it was generally covered in the land side cost estimate. Costs for installation of a mooring buoy system as described in this report are not included in this cost estimate.

Table 10 estimates the total project cost for both Option A and Option B. Table 11 provides the acreage by region to estimate the clearance rates shown in Table 12. Both plans include long-term clearance costs projected out to 10 years. Yearly labor costs increase at 5% per year. Annual operating costs are estimated at 17.5% of annual labor costs and include vessel charters and associated expenses, transportation, equipment repairs, service, and replacement, procurement of specialized equipment as well as supplies and utilities. Mobilization costs of $1,500,000 include project and operations planning, marine mammal mobilization, communications and navigation systems development. Demobilization costs are for clean up of the job site after the project is complete. Long term follow-up is an allocation for annual survey to check for newly uncovered UXO. A 10% contingency provision is made on top of the overall annual cost. The total cost of Option A clearance is $185,864,870. The total cost of Option B clearance at 10 years is $102,494,181.

TABLE 10

Estimate of Total Project Cost for

Option A and B

Option A

Annual Costs	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	TOTAL
Labor	11,313,939	11,879,636	12,473,618	13,097,299	13,752,164	14,439,772	15,161,760	15,919,848	16,715,841	17,551,633	142,305,509
Operating Expenses	1,979,939	2,078,936	2,182,883	2,292,027	2,406,629	2,526,960	2,653,308	2,785,973	2,925,272	3,071,536	24,903,464
Mobiliaztion	1,500,000										1,500,000
Demobilization										250,000	250,000
Long Term Follow-Up											0
10% Contingency	1,479,388	1,395,857	1,465,650	1,538,933	1,615,879	1,696,673	1,781,507	1,870,582	1,964,111	2,087,317	16,870,897
Total Annual Costs	16,273,266	15,354,429	16,122,151	16,928,258	17,774,671	18,663,405	19,596,575	20,576,404	21,605,224	22,960,485	
										TOTAL COST AT 10 YEARS	185,854,870

Option B

Annual Costs	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	TOTAL
Labor	11,313,939	11,879,636	12,473,618	13,097,299	13,752,164	14,439,772					76,956,427
Operating Expenses	1,979,939	2,078,936	2,182,883	2,292,027	2,406,629	2,526,960					13,467,375
Mobiliaztion	1,500,000										1,500,000
Demobilization						250,000					250,000
Long Term Follow-Up							250,000	250,000	250,000	250,000	1,000,000
10% Contingency	1,479,388	1,395,857	1,465,650	1,538,933	1,615,879	1,721,673	25,000	25,000	25,000	25,000	9,317,380
Total Annual Costs	16,273,266	15,354,429	16,122,151	16,928,258	17,774,671	18,938,405	275,000	275,000	275,000	275,000	
										TOTAL COST AT 10 YEARS	102,491,181

Table 11

KAHO`OLAWE UNDERWATER CLEARANCE GDSI 93.07.21

REGION	ACRES		% REGION	TOTAL		% ISLAND
NORTH				1043	ac.	14%
Kuheia	150	ac.	14%			
Kuheia mooring - Cat 3	18	ac.	2%			
Kuheia extension	56	ac.	5%			
non-SDA	819	ac.	79%			
NORTHEAST				783	ac.	11%
Hakioawa	81	ac.	10%			
Hakioawa mooring - Cat 3	14	ac.	2%			
non-SDA	688	ac.	88%			
EAST				332	ac.	5%
Kanapou	148	ac.	45%			
non-SDA	184	ac.	55%			
SOUTHEAST				436	ac.	6%
non-SDA	436	ac.	100%			
SOUTH				303	ac.	4%
Kamohio	18	ac.	6%			
non-SDA	285	ac.	94%			
SOUTHWEST				1144	ac.	16%
Hana Kanaia (part)	668	ac.	58%			
Hana Kanaia mooring - Cat 3	39	ac.	3%			
non-SDA	437	ac.	38%			
WEST				2276	ac.	31%
Hana Kanaia (part)	1980	ac.	87%			
Honokoa	62	ac.	3%			
non-SDA	234	ac.	10%			
NORTHWEST				942	ac.	13%
Ahupu	87	ac.	9%			
non-SDA	855	ac.	91%			
	TOTAL			7259	ac.	100%

Note: All clearance acreages are calculated using flat map area.
Actual surface area can be estimated by adding 5% to these acreages.

ALTERNATE BREAKDOWN			% ISLAND	+ 5%	
non-SDA - Cat 1	3938	ac.	54.3%	4135	ac.
SDA - Cat 2	3250	ac.	44.8%	3413	ac.
SDA heavy mooring - Cat 3	71	ac.	1.0%	75	ac.
total	7259	ac.	100.0%	7622	ac.

TABLE 12

ESTIMATE OF CLEARANCE RATE FOR CLEARANCE OPTIONS A AND B

Estimated Time to complete Option A – (Clear all waters to Cat 2)

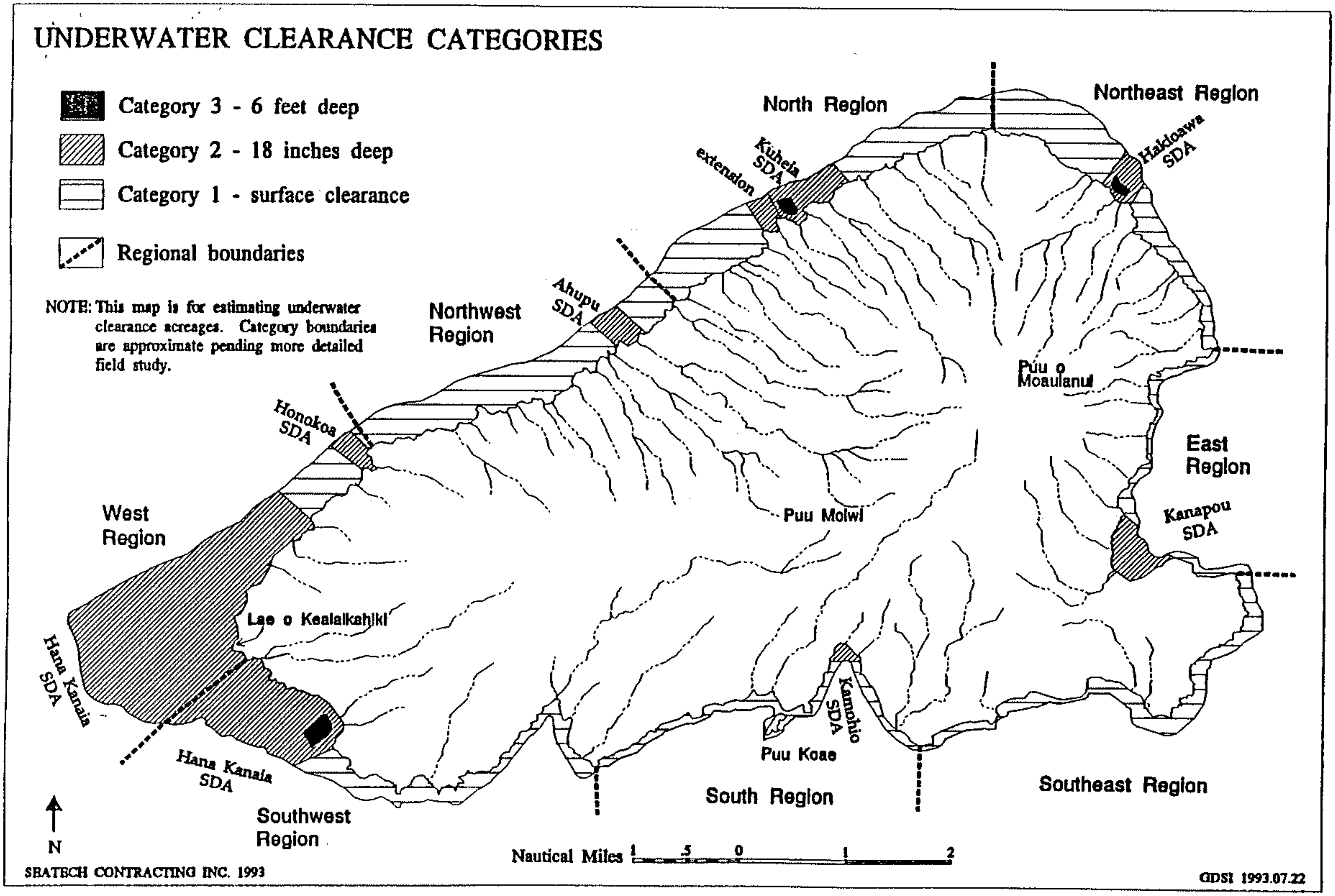
Work Group	Clearance Activity	Acres	Acres /day	Work Days	Work Years
1	CAT 1	7259	8.0	907	3.6
1	Conversion (1)			125	.05
1	CAT 2	2700	2.0	1350	5.4
		Group 1 total			9.5
11	CAT 2	4488	2.0	2244	9.0
11	CAT 3	71	.05	142	.06
		Group 11 total			9.6
		Start–up			.04
		Total Clearance Time			10.0

Estimated Time to complete Option B –(Clear all DSA's to Cat 2)

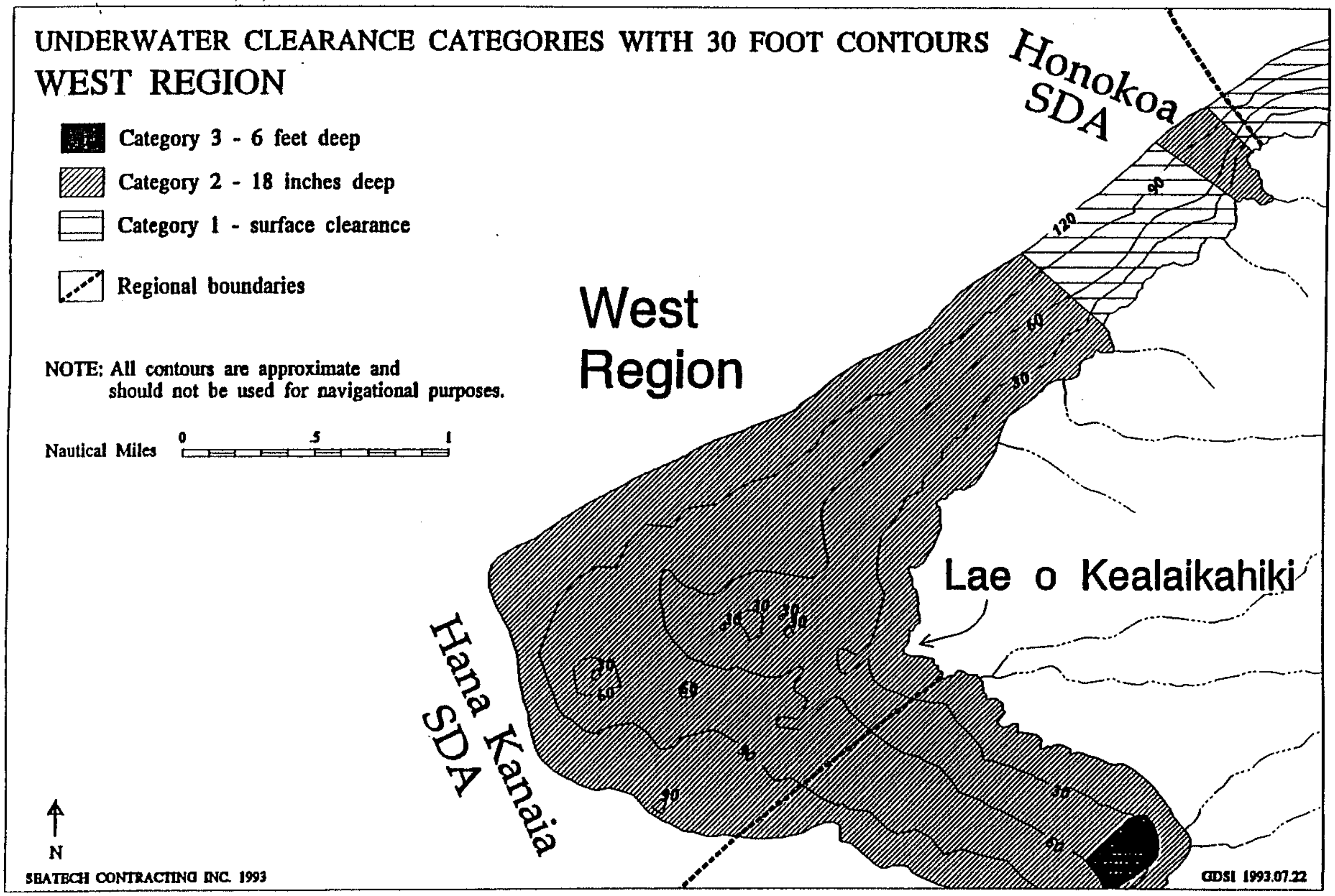
Work Group	Clearance Activity	Acres	Acres /day	Work Days	Work Years
1	CAT 1	7259	8.0	907	3.6
1	Conversion (1)			125	.05
1	CAT 2	750	2.0	375	1.5
		Group 1 total			5.6
11	CAT 2	2500	2.0	1250	5.0
11	CAT 3	71	.05	142	.06
		Group 11 total			5.6
		Start–up			.04
		Total Clearance Time			6.0

NOTES:

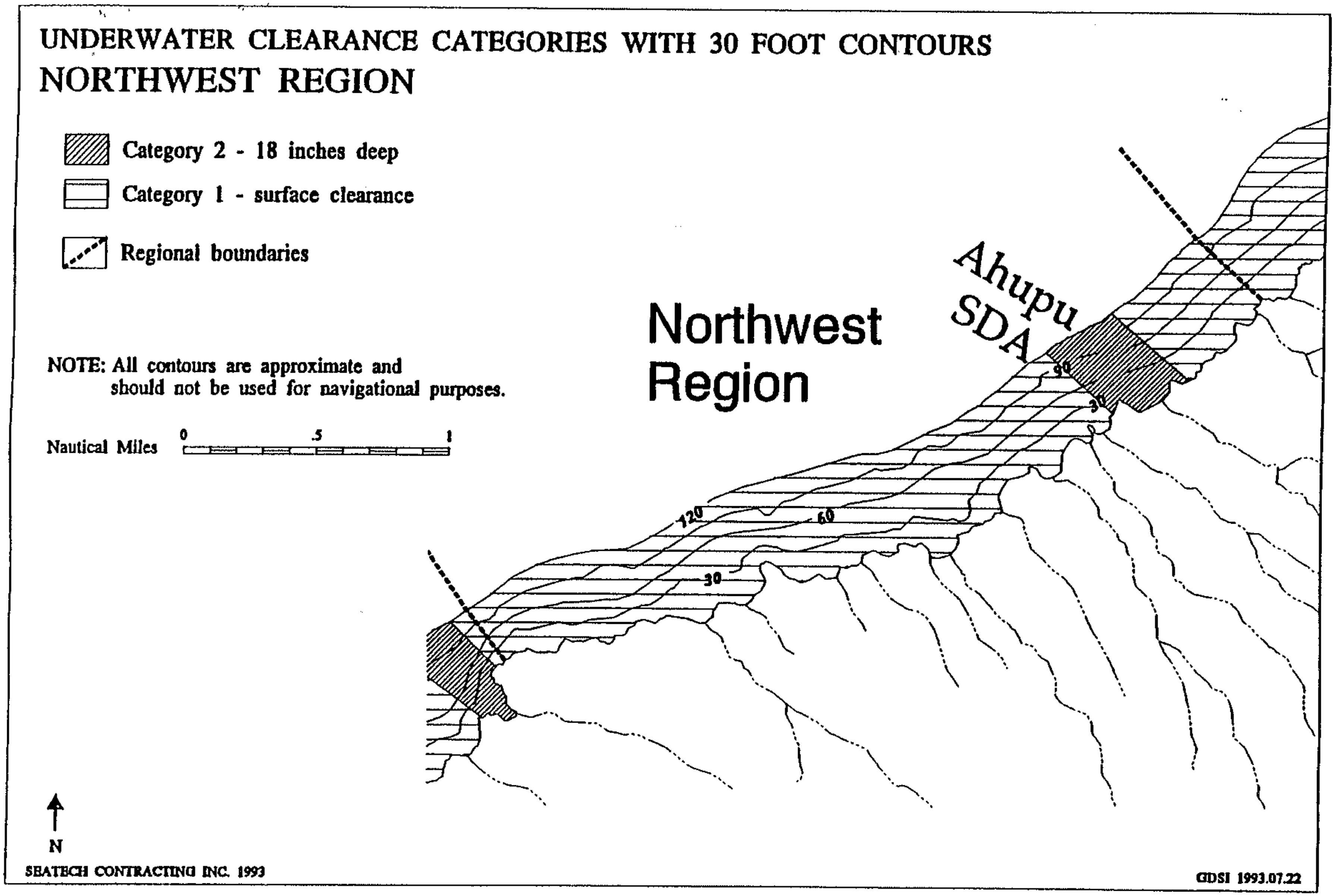
(1) Completing the Cat 1 task first, will dispose of the proud UXO, the UXO we assume to be most dangerous since it is exposed to contact by man. This task will be completed in 3.6 years. Upon completion of this task, the Work Group 1 biosystems, made up of a team of dolphins, will be re–trained for Cat 2 clearance, and assist Work Group 11 in locating buried UXO. This plan maximizes safety and efficiency. It should also be noted that biosystems work best when specializing on either Cat 1 or Cat 2 tasks. It is possible to accomplish these tasks concurrently, but it is not as efficient.


UNDERWATER CLEARANCE CATEGORIES
Category 3 - 6 feet deep
Category 2 - 18 inches deep
Category 1 - surface clearance
Regional boundaries
NOTE: This map is for estimating underwater clearance acreages. Category boundaries are approximate pending more detailed field study.
North Region
Northeast Region
Hakioawa SDA
Kuheia SDA
extension
Ahupu SDA
Northwest Region
Honokoa SDA
Puu o Moaulanui
East Region
Kanapou SDA
West Region
Puu Moiwi
Lae o Kealaikahiki
Hana Kanaia SDA
Hana Kanaia SDA
Kamohio SDA
Puu Koae
South Region
Southeast Region
Southwest Region
N
Nautical Miles 1 .5 0 1 2
SEATECH CONTRACTING INC. 1993
GDSI 1993.07.22

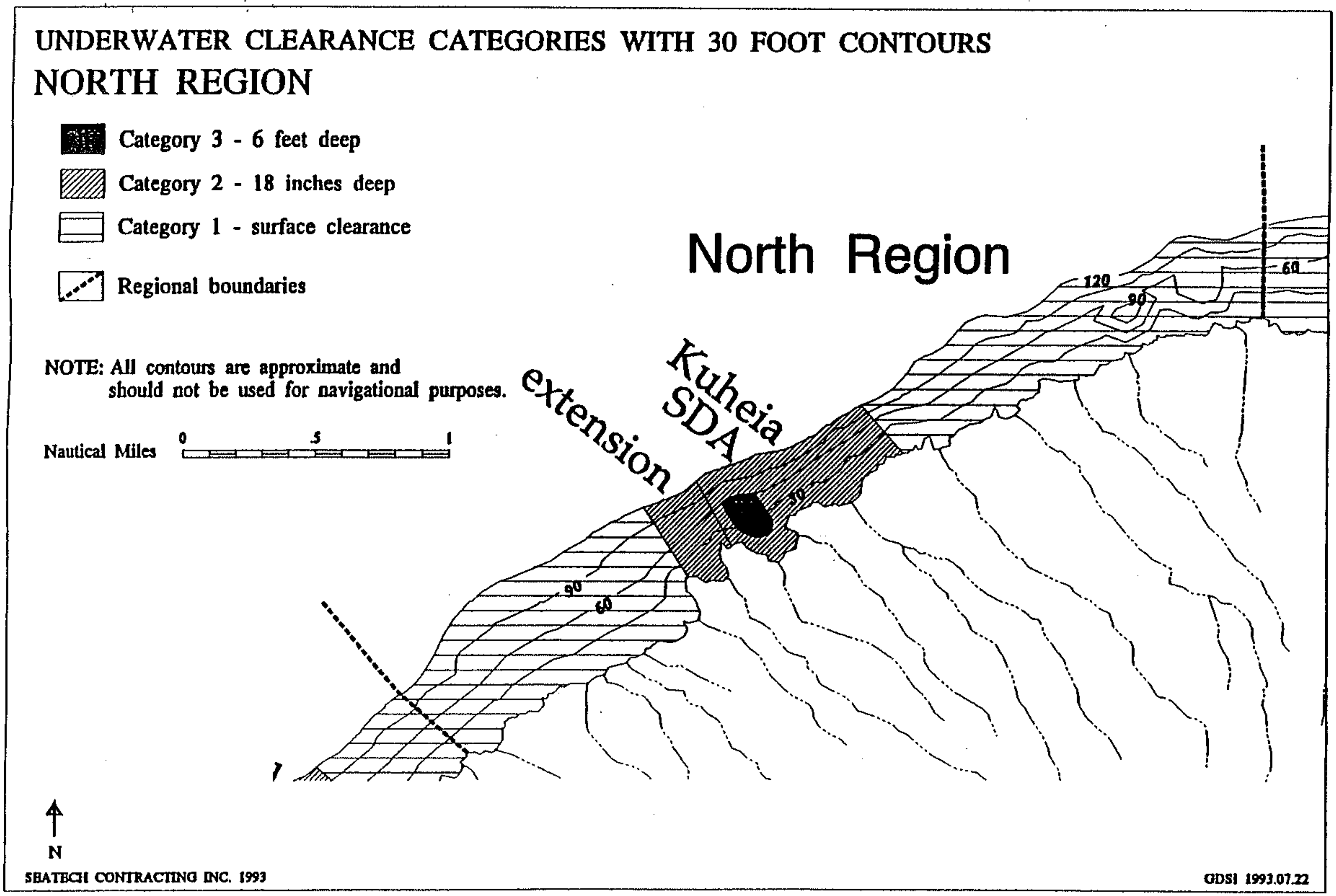
MAP - 1


UNDERWATER CLEARANCE CATEGORIES WITH 30 FOOT CONTOURS
WEST REGION
Category 3 - 6 feet deep
Category 2 - 18 inches deep
Category 1 - surface clearance
Regional boundaries
NOTE: All contours are approximate and should not be used for navigational purposes.
Nautical Miles
0
.5
1
N
SEATECH CONTRACTING INC. 1993
GDSI 1993.07.22
Honokoa SDA
West Region
Lae o Kealaikahiki
Hana Kanaia SDA
90
120
60
30

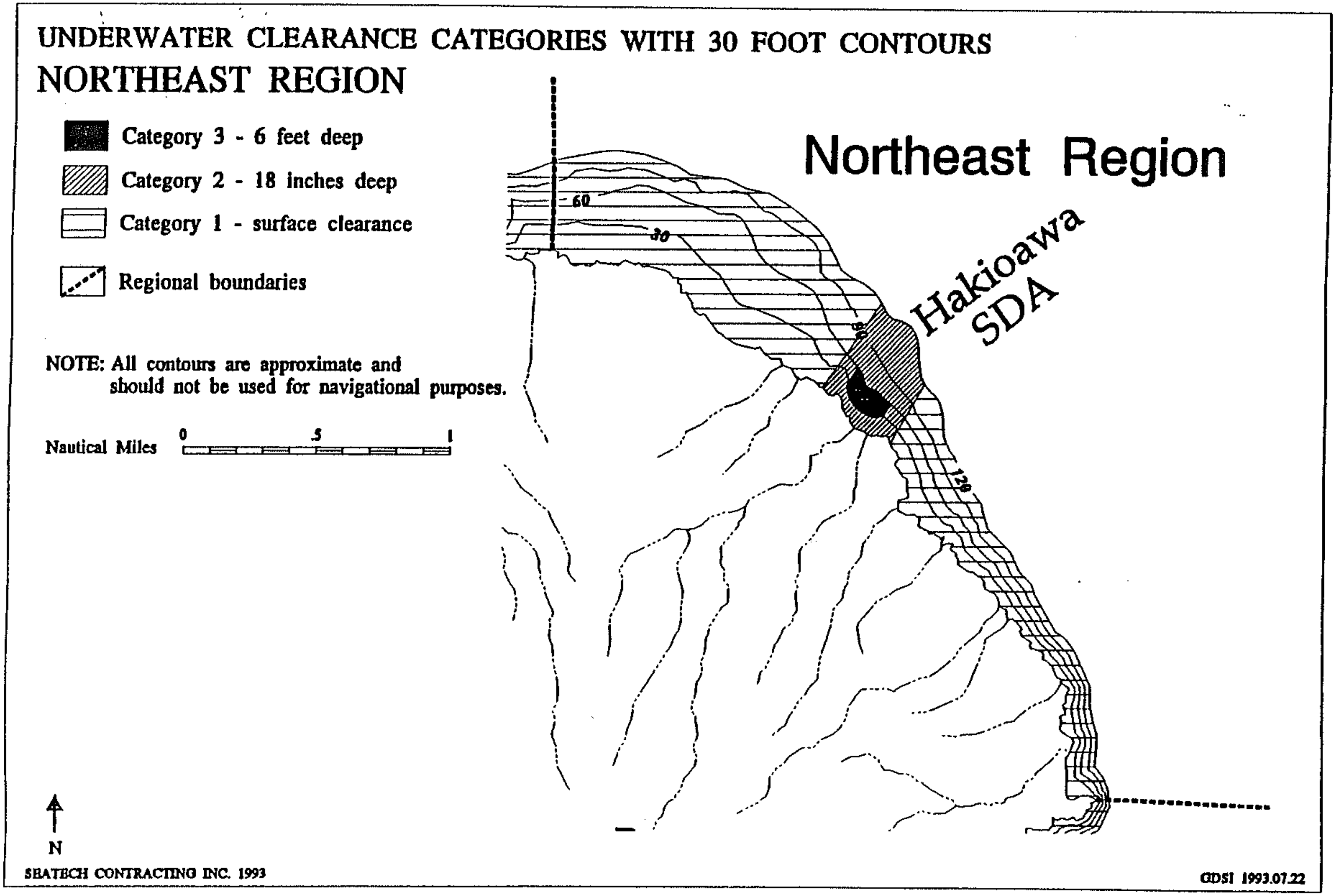
MAP - 2


UNDERWATER CLEARANCE CATEGORIES WITH 30 FOOT CONTOURS
NORTHWEST REGION
Category 2 - 18 inches deep
Category 1 - surface clearance
Regional boundaries
NOTE: All contours are approximate and should not be used for navigational purposes.
Nautical Miles
0
.5
1
Northwest Region
Ahupu SDA
90
30
120
60
30
N
SEATECH CONTRACTING INC. 1993
GDSI 1993.07.22

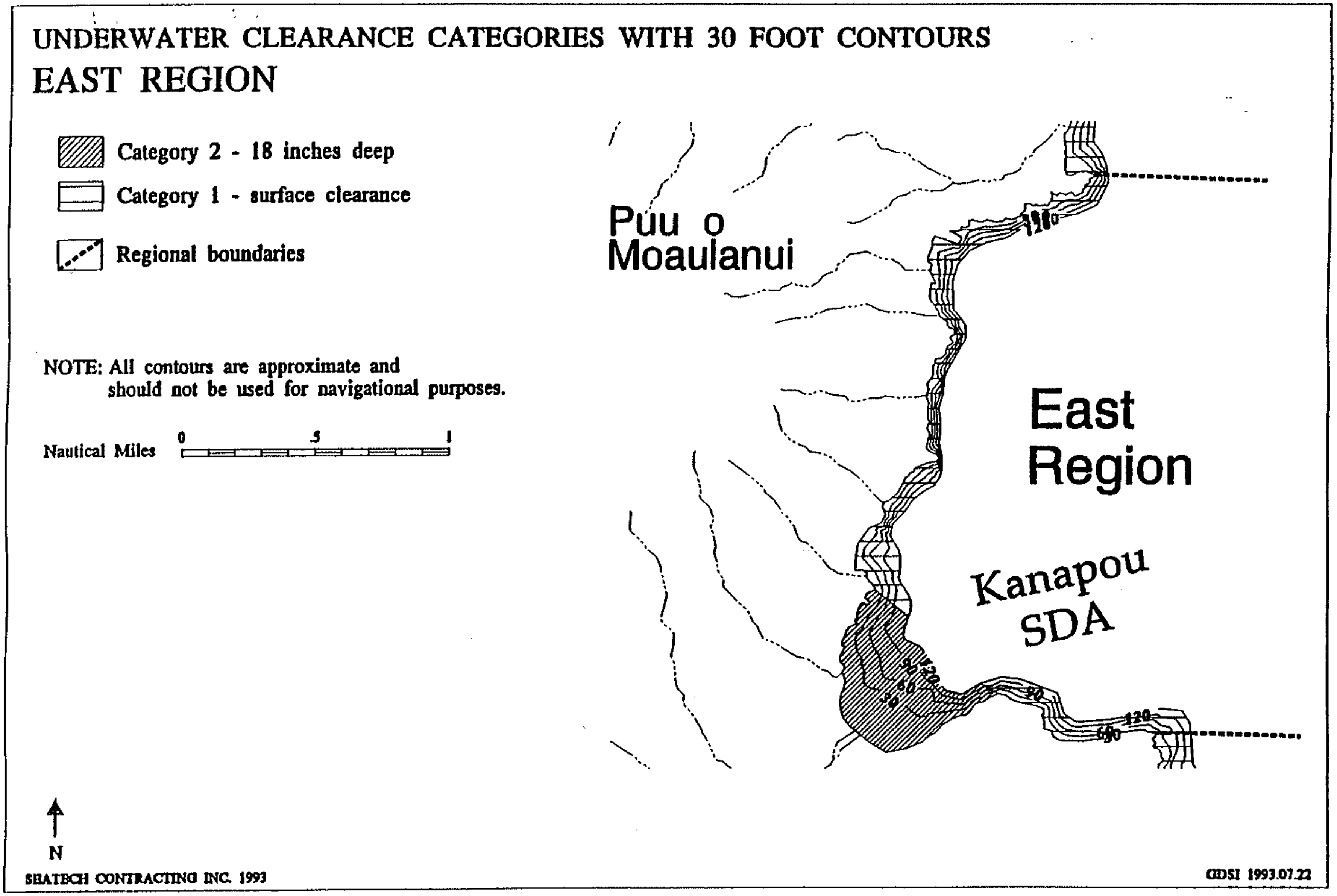
MAP - 3


UNDERWATER CLEARANCE CATEGORIES WITH 30 FOOT CONTOURS
NORTH REGION
Category 3 - 6 feet deep
Category 2 - 18 inches deep
Category 1 - surface clearance
Regional boundaries
NOTE: All contours are approximate and should not be used for navigational purposes.
Nautical Miles
0
.5
1
North Region
Kuheia SDA
extension
120
90
60
30
90
60
N
SEATECH CONTRACTING INC. 1993
GDSI 1993.07.22

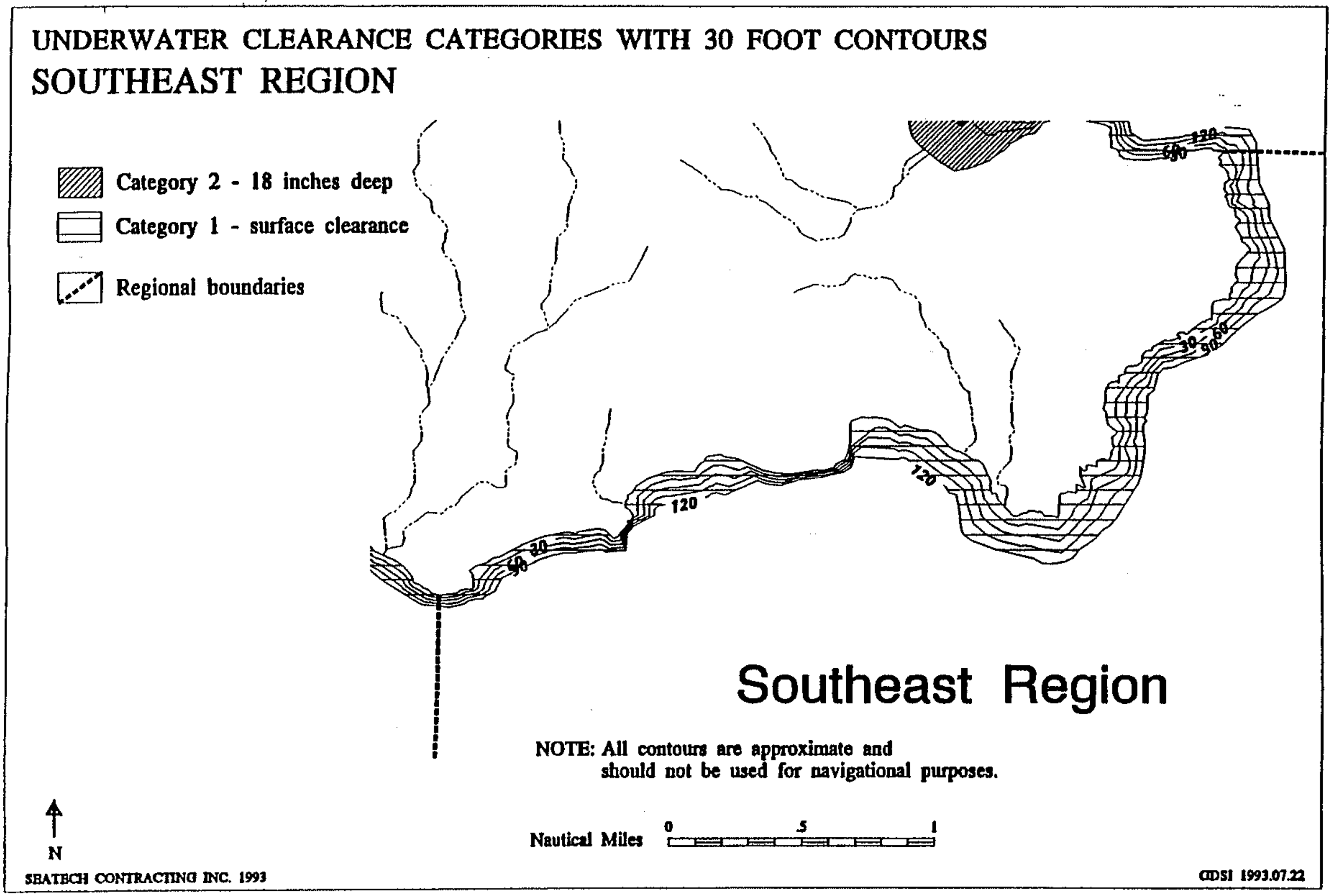
MAP - 4


UNDERWATER CLEARANCE CATEGORIES WITH 30 FOOT CONTOURS
NORTHEAST REGION
Category 3 - 6 feet deep
Category 2 - 18 inches deep
Category 1 - surface clearance
Regional boundaries
NOTE: All contours are approximate and should not be used for navigational purposes.
Nautical Miles
0
.5
1
Northeast Region
Hakioawa SDA
60
30
90
120
N
SEATECH CONTRACTING INC. 1993
GDSI 1993.07.22

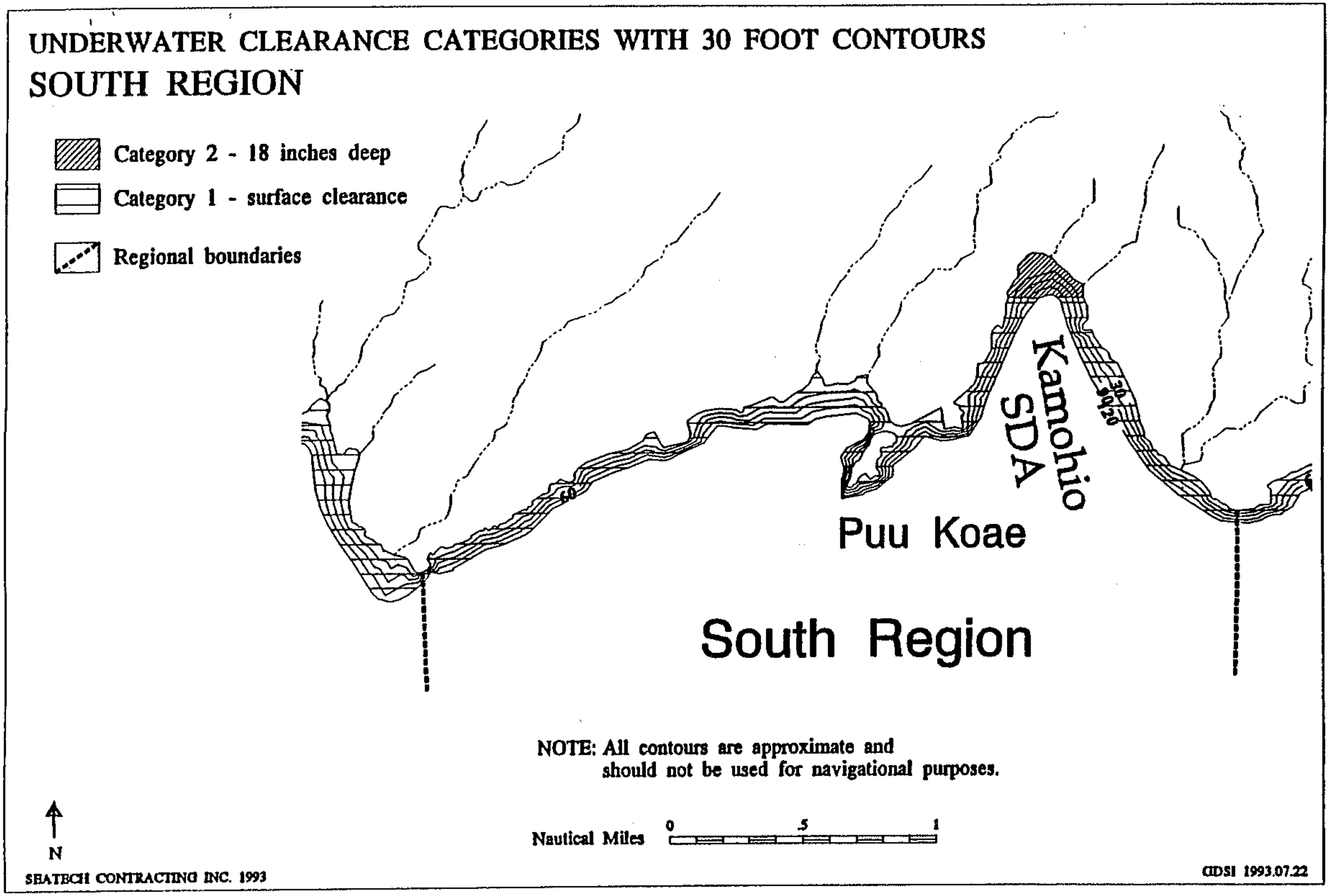
MAP - 5

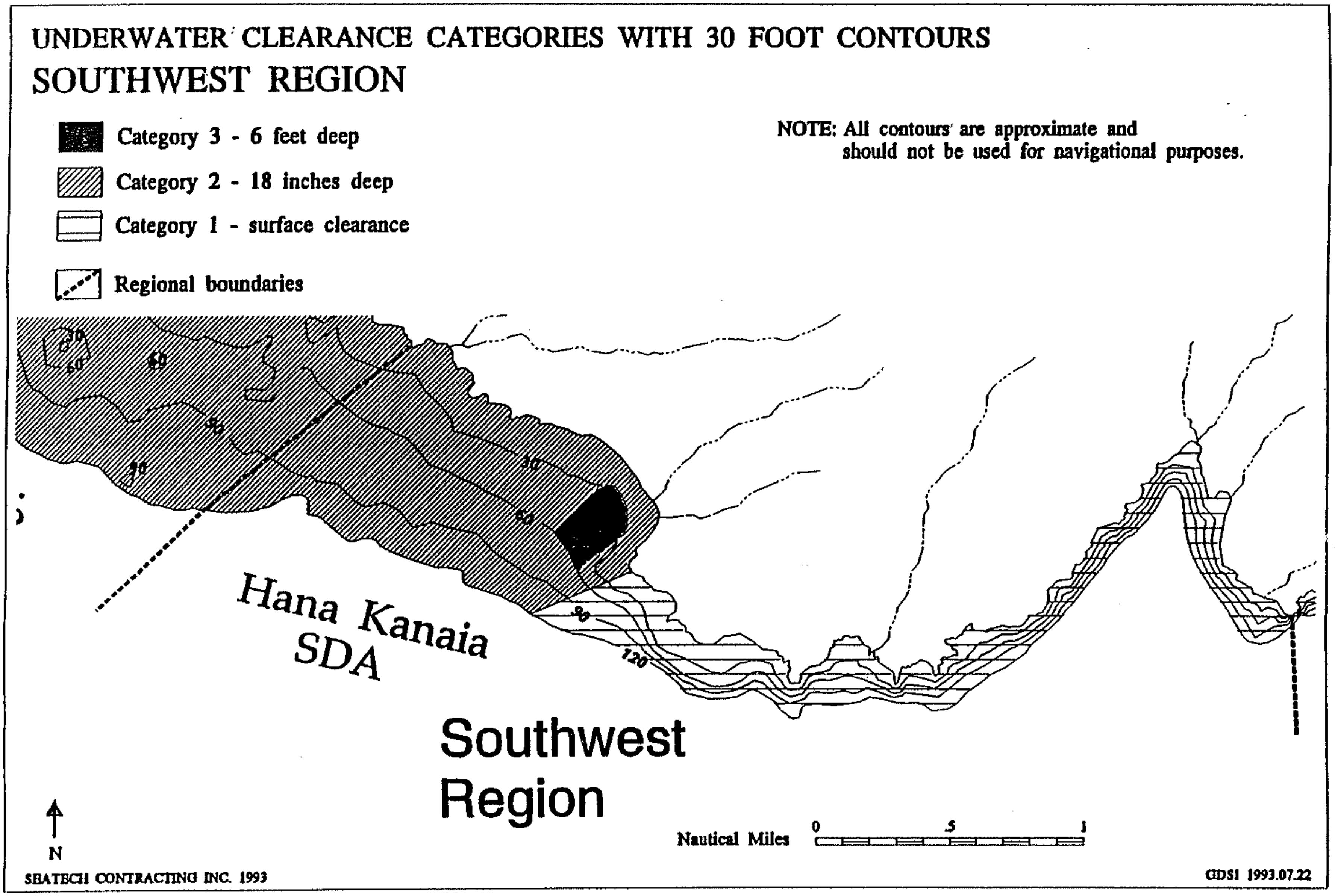

UNDERWATER CLEARANCE CATEGORIES WITH 30 FOOT CONTOURS
EAST REGION
Category 2 - 18 inches deep
Category 1 - surface clearance
Regional boundaries
NOTE: All contours are approximate and should not be used for navigational purposes.
Nautical Miles
0
.5
1
Puu o Moaulanui
East Region
Kanapou SDA
N
SEATECH CONTRACTING INC. 1993
GDSI 1993.07.22

MAP - 6


UNDERWATER CLEARANCE CATEGORIES WITH 30 FOOT CONTOURS
SOUTHEAST REGION
Category 2 - 18 inches deep
Category 1 - surface clearance
Regional boundaries
120
60
90
30
Southeast Region
NOTE: All contours are approximate and should not be used for navigational purposes.
Nautical Miles
0
.5
1
N
SEATECH CONTRACTING INC. 1993
CDSI 1993.07.22

MAP - 7


UNDERWATER CLEARANCE CATEGORIES WITH 30 FOOT CONTOURS
SOUTH REGION
Category 2 - 18 inches deep
Category 1 - surface clearance
Regional boundaries
Kamohio SDA
Puu Koae
South Region
NOTE: All contours are approximate and should not be used for navigational purposes.
Nautical Miles
0
.5
1
N
SEATECH CONTRACTING INC. 1993
GDSI 1993.07.22



UNDERWATER CLEARANCE CATEGORIES WITH 30 FOOT CONTOURS
SOUTHWEST REGION
Category 3 - 6 feet deep
Category 2 - 18 inches deep
Category 1 - surface clearance
Regional boundaries
NOTE: All contours are approximate and should not be used for navigational purposes.
Hana Kanaia SDA
Southwest Region
30
60
90
120
N
Nautical Miles
0
.5
1
SEATECH CONTRACTING INC. 1993
GDSI 1993.07.22

MAP - 9

APPENDIX A

Participants in Oral History

SCI wishes to acknowledge the generous contributions of time and invaluable experience by all of those interviewed for the oral history.

Capt. Mit Roth COMNAVBASE
Capt. Tom Stone USNR EOD
Dave Hart USN EOD (retired)
Stan Ryley USN EOD (retired)
Greg Ford USN EOD (retired)
Lt. Nahoopii USN Seabee
Cdr. George Demotropolis USN, Commanding Officer EODMUONE
Capt. Ted McCarley USN, Commodore, EODGRUONE
Lt. Greg Wheelock USN, Operations Officer EODMUONE
LCDR Steve Dehart USN, Operations Officer EODMUONE
Norm Garon USN EOD (Retired)
Sgt. Redfield USMC EOD KMCAS
Byron Donaldson USMC EOD (Retired)
Capt. Jerome Heck USN EOD (Retired)
Capt. C.K. Naylor USN EOD (Retired)
Jim Wingo USN EOD (Retired)
Morris Arakawa FASFACT Pearl Harbor
Brian Kanenaka DLNR, Aquatic Resources Division
Dave Eckart DLNR, Aquatic Resources Division

APPENDIX B:

Observation Summary and Data Reduction

The following is an explanation of how to read the succeeding tables. These tables were created in Quattro Pro 4.0 and are available on disk. They can be reformatted for Lotus 2.X and 3.X.

One table was prepared for each of the 7 regions where observations were made.

In the tables, data are presented to more significant figures than accuracy suggests. For practical purposes, two significant figures is meaningful.

COLUMN	DESCRIPTION
REGION	The offshore search was divided into 8 regions denoted by E (East), SE (South East), . . . etc.
SECTION	To facilitate the search, each region was divided into sections of approximately .5 NM alongshore, from the shoreline to a depth of 120 feet. These were numbered, starting from 1 for each region. Each of these was subdivided in the search, usually by a swath of 30 feet, at a constant depth, thus running approximately parallel to the shoreline. Each line of the table represents one search swath.
WIDTH	The width of the search swath, usually 30 feet.
LENGTH	The length of each search swath, usually .5 nautical miles.

AREA

The length of each swath times the width, usually 2.09 Acres. There were 3 swathes that differed significantly from the above. The acreage of these was determined by the observers aboard ship. For these the width and length is not shown, only the area is presented.

OBSERVED

This is the number of UXO observed for the individual swaths.

% OBSV-PROUD

This is an estimate of the ability of the observer to find the UXO. It is his Hit Per Cent. A figure of 90% means the observer believed, under the conditions at that swath, that if UXO were there, he would have found 90% of the proud UXO and missed 10% of the proud UXO. This is the combined effect of water clarity, coral growth, lighting conditions, etc., at the individual site.

PROUD

This is the calculated value of the number of proud UXO that should be in the swath. It is obtained by dividing the actual number observed (OBSERVED) by the Hit Per Cent (% OBSV-PROUD).

% HARD

This is a figure that will be used to estimate the total number of UXO as compared to the proud ones. This is a sum of the % rock bottom plus the % coral bottom plus one half of the % rubble. It excludes the % silt bottom plus the % mud bottom plus one half of the % rubble bottom. The use of this follows the assumption that denser items tend to get buried in the nearshore because of drifting sand, siltation and slides. Evidence of these environmental conditions was found during the search.

TOTAL

This is an estimate of the total number of UXO, both proud and buried. It is computed by dividing PROUD by % HARD.

%OBSV*AREA	This is a term used to normalize the readings in this swath with the other swaths. It is the product of % OBSV-PROUD and AREA. It is not important by itself.
%HARD*AREA	This is a term used to normalize the readings in this swath with the other swathes. It is the product of % HARD and AREA. It is not important by itself.
OBSV/AREA	This is OBSERVED divided by AREA. It is the density of UXO observed per acre for each swath. It is used with the sampling models.
PROUD/AREA	This is the number PROUD divided by the swath AREA. It is the density of proud UXO per acre for the swath. It is used with the sampling models.
TOTAL/AREA	This is the TOTAL divided by the swath AREA. It is the density of the total number of UXO per acre for the swath. It is used with the sampling models.
Below AREA	Total area searched.
Below OBSERVED	Total UXO observed
Below %OBSV-P	Average of column. This is not used in this analysis.
Below PROUD	Total for the column. This is not used in this analysis.
Below %HARD	Average of column. This is not used in this analysis.
Below TOTAL	Total for the column. This is not used in this analysis.
Below %OBS*AREA	This is the normalized value of the %OBSV-PROUD. It is the sum of the column divided by the area searched for each region.

Below %HRD*AREA	This is the normalized value of the % HARD. It is the sum of the column divided by the area searched for each region.
Below OBSV/AREA	This is the mean sampled density of UXO per acre for the region.
Belw PROUD/AREA	This is the mean sampled density of proud UXO per acre for the region.
Belw TOTAL/AREA	This is the mean sampled density of the total number of UXO per acre for this region.

Below the table there are three other rows of figures. These summarize the search for the region. These are based on total count and total area for each region. They do not incorporate any sampling data.

WEIGHTED AVERAGES. These are the weighted averages of the search using the results at the base of the two inner product columns, %OBSV*AREA (proud) and %HARD*AREA.

In the OBSERVED column is the actual total count.

In the PROUD column is the computed value of the total number of proud UXO that would be seen by the perfect observer. It is OBSERVED divided by the normalized %OBSV-PROUD.

In the TOTAL column is the computed value of the total number of UXO that would be seen by the perfect observer if none of them were buried. It is Proud divided by the normalized % HARD. The number of buried UXO is the difference between TOTAL and PROUD.

PER ACRE. These are the above numbers of OBSERVED, PROUD and TOTAL divided by the total search AREA. These are the number of UXO per acre.

TOTAL. These are the total numbers of OBSERVED, PROUD and TOTAL for the region. They were calculated by multiplying the numbers per acre by the total number of acres.

Some of the T-Test results are in the last four columns on the right. Rather than itemizing them it is more important to compare three pair of figures.

The three average densities shown below PER ACRE in columns OBSERVED, PROUD and TOTAL should be compared to the three sampled means at the bottoms of columns OBSV/AREA, PROUD/AREA and TOTAL/AREA. It is this writer's (Lester Q. Spielvogel) opinion that the sampled means are more indicative of the true values. In the body of the report we presented a short summary showing comparisons of the observed density (as if the data in each region was from one big sample) compared to treating the data as sampled data. The later was done with both a T-Test model and a Poisson distribution model.

In the data to the right we see how the confidence level effects the largest expected density. In the third row is the average density as computed by treating the data as sampled data. The bottom row (UPPER AVERAGE) shows (by the T-Test) the maximum we would expect the density of the region to be for different confidence levels (80%, 90% and 95%). These densities are considerably higher than the simple density (OBSERVED/AREA SEARCHED) used in the report body. The differences are related to the standard deviation of the collected data and the number of samples. The first is an attribute of the site modified by the size of the sampled region. No modification of the technique could have altered this without great expense. The second factor could have been increased by not doing the three large search swaths and/or with a modest increase in resources. Although 10% of the test region was searched, less than 5% was adequately sampled in accordance with plans. We were aiming for 10% to 15%.

APPENDIX B: OBSERVATION SUMMARY AND DATA REDUCTION - SOUTHWEST REGION

REGION	SECTIO	WIDTH FT	LENGT NM	AREA	OBSERV	% OBSV-P	PROUD	% HAR	TOTAL	%OBSV*ARE	%HARD*AR	OBSV/AR	PROUD/AR	TOTAL/AREA
SW	3	30	0.5	2.09	0	90.00%	0.00	90.00%	0.00	188.31%	188.31%	0.000	0.000	0.000
SW	3	30	0.5	2.09	0	90.00%	0.00	90.00%	0.00	188.31%	188.31%	0.000	0.000	0.000
SW	3	30	0.5	2.09	0	80.00%	0.00	77.50%	0.00	167.38%	162.15%	0.000	0.000	0.000
SW	4	30	0.5	2.09	0	90.00%	0.00	90.00%	0.00	188.31%	188.31%	0.000	0.000	0.000
SW	4	30	0.5	2.09	0	90.00%	0.00	90.00%	0.00	188.31%	188.31%	0.000	0.000	0.000
SW	4	30	0.5	2.09	0	80.00%	0.00	77.50%	0.00	167.38%	162.15%	0.000	0.000	0.000
SW	5	30	0.5	2.09	2	90.00%	2.22	90.00%	2.47	188.31%	188.31%	0.956	1.062	1.180
SW	5	30	0.5	2.09	0	90.00%	0.00	90.00%	0.00	188.31%	188.31%	0.000	0.000	0.000
SW	5	30	0.5	2.09	0	80.00%	0.00	77.50%	0.00	167.38%	162.15%	0.000	0.000	0.000
SW	6	30	0.5	2.09	1	90.00%	1.11	90.00%	1.23	188.31%	188.31%	0.478	0.531	0.590
SW	6	30	0.5	2.09	1	90.00%	1.11	90.00%	1.23	188.31%	188.31%	0.478	0.531	0.590
SW	6	30	0.5	2.09	0	80.00%	0.00	77.50%	0.00	167.38%	162.15%	0.000	0.000	0.000
SW	6	30	0.5	2.09	0	80.00%	0.00	47.50%	0.00	167.38%	99.38%	0.000	0.000	0.000
SW	7	30	0.5	2.09	3	90.00%	3.33	77.50%	4.30	188.31%	162.15%	1.434	1.593	2.056
SW	7	30	0.5	2.09	3	90.00%	3.33	67.50%	4.94	188.31%	141.23%	1.434	1.593	2.360
SW	7	30	0.5	2.09	0	80.00%	0.00	27.50%	0.00	167.38%	57.54%	0.000	0.000	0.000
SW	8	30	0.5	2.09	0	80.00%	0.00	55.00%	0.00	167.38%	115.08%	0.000	0.000	0.000
SW	9	30	0.5	2.09	0	80.00%	0.00	10.00%	0.00	167.38%	20.92%	0.000	0.000	0.000
SW	8/9			265.00	10	85.00%	11.76	10.00%	117.65	22525.00%	2650.00%	0.038	0.044	0.444
SW		SEARCH		302.66	20	85.53%	23.38	69.74%	33.53	85.07%	17.85%	0.254	0.282	0.380
		WEIGHTED AVERAGES				WEIGHTED AVERAGES			WEIGHTED AVERAGES					
					20	85.07%	23.51	17.85%	131.74					
		PER ACRE				PER ACRE			PER ACRE					
					0.066	85.07%	0.078	17.85%	0.435					
						TOTAL			TOTAL		COVERAGE			
				1144	75.60		88.86		497.94		26.46% (3.29%)			

REGIO	SW		
COUNT	19		
AVERA	0.254		
STD	0.474		
STDS	0.487		
STDS/R	0.112		
CONFI	80.00%	90.00%	95.00%
"T"	1.33	1.734	2.101
T*STDS	0.148	0.194	0.235
% OF M	58.56%	76.35%	92.51%
UPPER	1.586	1.764	1.925
UPPER	0.402	0.447	0.488

APPENDIX B: OBSERVATION SUMMARY AND DATA REDUCTION - SOUTH REGION

REGION	SECTI	WIDTH FT	LENGT NM	AREA	OBSERV	% OBSV-P	PROUD	% HAR	TOTAL	%OBSV*AR	%HARD*A	OBSV/AR	PROUD/AR	TOTAL/AREA
S	1	30	0.5	2.09	0	90.00%	0.00	90.00%	0.00	188.31%	188.31%	0.000	0.000	0.000
S	1	30	0.5	2.09	0	90.00%	0.00	85.00%	0.00	188.31%	177.84%	0.000	0.000	0.000
S	1	30	0.5	2.09	0	80.00%	0.00	75.00%	0.00	167.38%	156.92%	0.000	0.000	0.000
S	1	30	0.5	2.09	0	60.00%	0.00	50.00%	0.00	125.54%	104.61%	0.000	0.000	0.000
S	2	30	0.5	2.09	0	90.00%	0.00	90.00%	0.00	188.31%	188.31%	0.000	0.000	0.000
S	2	30	0.5	2.09	0	90.00%	0.00	90.00%	0.00	188.31%	188.31%	0.000	0.000	0.000
S	2	30	0.5	2.09	0	80.00%	0.00	75.00%	0.00	167.38%	156.92%	0.000	0.000	0.000
S	2	30	0.5	2.09	0	80.00%	0.00	65.00%	0.00	167.38%	136.00%	0.000	0.000	0.000
S	2	30	0.5	2.09	0	60.00%	0.00	45.00%	0.00	125.54%	94.15%	0.000	0.000	0.000
S	3	30	0.5	2.09	0	90.00%	0.00	45.00%	0.00	188.31%	94.15%	0.000	0.000	0.000
S	3	30	0.5	2.09	0	80.00%	0.00	45.00%	0.00	167.38%	94.15%	0.000	0.000	0.000
S	3	30	0.5	2.09	0	70.00%	0.00	30.00%	0.00	146.46%	62.77%	0.000	0.000	0.000
S	3	30	0.5	2.09	0	60.00%	0.00	20.00%	0.00	125.54%	41.85%	0.000	0.000	0.000
S	3	30	0.5	2.09	0	50.00%	0.00	20.00%	0.00	104.61%	41.85%	0.000	0.000	0.000
S	4	30	0.5	2.09	2	95.00%	2.11	75.00%	2.81	198.77%	156.92%	0.956	1.006	1.342
S	4	30	0.5	2.09	0	90.00%	0.00	75.00%	0.00	188.31%	156.92%	0.000	0.000	0.000
S	4	30	0.5	2.09	0	70.00%	0.00	40.00%	0.00	146.46%	83.69%	0.000	0.000	0.000
S	4	30	0.5	2.09	0	60.00%	0.00	30.00%	0.00	125.54%	62.77%	0.000	0.000	0.000
S	4	30	0.5	2.09	0	50.00%	0.00	30.00%	0.00	104.61%	62.77%	0.000	0.000	0.000
S	5	30	1.5	6.28	0	95.00%	0.00	100.00	0.00	596.30%	627.69%	0.000	0.000	0.000
S	5	30	1.5	6.28	1	90.00%	1.11	97.50%	1.14	564.92%	611.99%	0.159	0.177	0.182
S	5	30	0.5	2.09	0	90.00%	0.00	95.00%	0.00	188.31%	198.77%	0.000	0.000	0.000
S	5	30	0.5	2.09	0	80.00%	0.00	90.00%	0.00	167.38%	188.31%	0.000	0.000	0.000
S	6	30	0.5	2.09	0	95.00%	0.00	97.50%	0.00	198.77%	204.00%	0.000	0.000	0.000
S	6	30	0.5	2.09	0	90.00%	0.00	100.00	0.00	188.31%	209.23%	0.000	0.000	0.000
S	6	30	0.5	2.09	0	90.00%	0.00	100.00	0.00	188.31%	209.23%	0.000	0.000	0.000
S	6	30	0.5	2.09	2	80.00%	2.50	85.00%	2.94	167.38%	177.84%	0.956	1.195	1.406
S	6	30	0.5	2.09	0	70.00%	0.00	85.00%	0.00	146.46%	177.84%	0.000	0.000	0.000
S	SEARCH			66.95	5	79.11%	6.32	68.75%	9.19	80.78%	72.50%	0.074	0.085	0.105
	WEIGHTED AVERAGES					WEIGHTED AVERAGES			WEIGHTED AVERAGES					
					5	80.78%	6.19	72.50%	8.54					
	PER ACRE					PER ACRE			PER ACRE					
					0.075	80.78%	0.092	72.50%	0.128		GREAT			
						TOTAL			TOTAL		COVERAGE !			
				303	22.63		28.01		38.64		22.10%			

REGIO	S		
COUNT	28		
AVERA	0.074		
STD	0.246		
STDS	0.251		
STDS/	0.047		
CONFI	80.00%	90.00%	95.00%
"T"	1.314	1.703	2.052
T*STD	0.062	0.081	0.097
% OF	84.23%	109.17%	131.54%
UPPER	1.842	2.092	2.315
UPPER	0.136	0.155	0.171

APPENDIX B: OBSERVATION SUMMARY AND DATA REDUCTION - EAST REGION

REGION	SECTI	WIDTH FT	LENGT NM	AREA	OBSER	% OBSV-P	PROU	% HAR	TOTAL	%OBSV*AR	%HARD*A	OBSV/AR	PROUD/A	TOTAL/AREA
E	1	30	0.5	2.09	0	95.00%	0.00	95.00%	0.00	198.77%	198.77%	0.000	0.000	0.000
E	1	30	0.5	2.09	0	90.00%	0.00	92.50%	0.00	188.31%	193.54%	0.000	0.000	0.000
E	2	30	0.5	2.09	0	95.00%	0.00	97.50%	0.00	198.77%	204.00%	0.000	0.000	0.000
E	3	30	0.25	1.05	4	95.00%	4.21	97.50%	4.32	99.38%	102.00%	3.824	4.025	4.128
E	6	30	0.5	2.09	0	50.00%	0.00	30.00%	0.00	104.61%	62.77%	0.000	0.000	0.000
E	7	30	0.5	2.09	0	95.00%	0.00	95.00%	0.00	198.77%	198.77%	0.000	0.000	0.000
				======	======	=======	======	======	======	========	=======	======	=======	=========
E	SEARCH			11.51	4	86.67%	4.62	84.58%	5.46	85.91%	83.41%	0.637	0.671	0.688
												======	=======	=========
	WEIGHTED AVERAGES					WEIGHTED AVERAGES			WEIGHTED AVERAGES					
					4	85.91%	4.66	83.41%	5.58					
	PER ACRE					PER ACRE			PER ACRE					
					0.348	85.91%	0.405	83.41%	0.485		POOR			
						TOTAL			TOTAL		COVERAGE			
				332	115.40		134.33		161.05		3.47%			

REGIO	E		
COUN	6		
AVERA	0.637		
STD	1.425		
STDS	1.561		
STDS/	0.637		
CONFI	80.00%	90.00%	95.00%
"T"	1.476	2.015	2.571
T*STD	0.941	1.284	1.638
% OF	147.60	201.50	257.10%
UPPER	2.476	3.015	3.571
UPPER	1.578	1.921	2.276

APPENDIX B: OBSERVATION SUMMARY AND DATA REDUCTION - NORTHEAST REGION

REGION	SECTI	WIDTH FT	LENGT NM	AREA	OBSER	% OBSV-P	PROU	% HAR	TOTAL	%OBSV*AR	%HARD*A	OBSV/AR	PROUD/A	TOTAL/AREA
NE	1	30	0.5	2.09	0	90.00%	0.00	30.00%	0.00	188.31%	62.77%	0.000	0.000	0.000
NE	3	30	0.25	1.05	0	60.00%	0.00	5.00%	0.00	62.77%	5.23%	0.000	0.000	0.000
NE	4	30	0.5	2.09	0	90.00%	0.00	30.00%	0.00	188.31%	62.77%	0.000	0.000	0.000
NE	4	30	0.5	2.09	0	95.00%	0.00	30.00%	0.00	198.77%	62.77%	0.000	0.000	0.000
NE	5	30	0.5	2.09	0	95.00%	0.00	30.00%	0.00	198.77%	62.77%	0.000	0.000	0.000
NE	5	30	0.5	2.09	0	95.00%	0.00	40.00%	0.00	198.77%	83.69%	0.000	0.000	0.000
NE	6	30	0.5	2.09	0	95.00%	0.00	30.00%	0.00	198.77%	62.77%	0.000	0.000	0.000
NE	6	30	0.5	2.09	0	95.00%	0.00	40.00%	0.00	198.77%	83.69%	0.000	0.000	0.000
				======	======	======	======	======	======	======	======	======	======	======
NE		SEARCH		15.69	0	89.38%	0.00	29.38%	0.00	91.33%	31.00%	0.000	0.000	0.000
												======	======	======
		WEIGHTED AVERAGES				WEIGHTED AVERAGES			WEIGHTED AVERAGES					
					0	91.33%	0.00	31.00%	0.00					
		PER ACRE				PER ACRE			PER ACRE					
					0.000	91.33%	0.000	31.00%	0.000		POOR			
						TOTAL			TOTAL		COVERAGE			
				783	0.00		0.00		0.00		2.00%			

REGIO	NE		
COUN	8		
AVERA	0.000		
STD	0.000		
STDS	0.000		
STDS/	0.000		
CONFI	80.00%	90.00%	95.00%
"T"	1.415	1.895	2.365
T*STD	0.000	0.000	0.000
% OF	N.A.	N.A.	N.A.
UPPER	N.A.	N.A.	N.A.
UPPER	N.A.	N.A.	N.A.

APPENDIX B: OBSERVATION SUMMARY AND DATA REDUCTION - NORTH REGION

REGION	SECTI	WIDTH FT	LENGT NM	AREA	OBSER	% OBSV-P	PROU	% HAR	TOTAL	%OBSV*AR	%HARD*A	OBSV/AR	PROUD/A	TOTAL/AREA
N	1	30	0.5	2.09	0	90.00%	0.00	80.00%	0.00	188.31%	167.38%	0.000	0.000	0.000
N	2	30	0.5	2.09	0	90.00%	0.00	80.00%	0.00	188.31%	167.38%	0.000	0.000	0.000
N	2			14.50	1	95.00%	1.05	45.00%	2.34	1377.50%	652.50%	0.069	0.073	0.161
N	2	30	0.5	2.09	0	75.00%	0.00	15.00%	0.00	156.92%	31.38%	0.000	0.000	0.000
N	3	30	0.5	2.09	0	90.00%	0.00	15.00%	0.00	188.31%	31.38%	0.000	0.000	0.000
N	4	30	0.5	2.09	0	90.00%	0.00	35.00%	0.00	188.31%	73.23%	0.000	0.000	0.000
N	5	30	0.5	2.09	0	90.00%	0.00	35.00%	0.00	188.31%	73.23%	0.000	0.000	0.000
N	6	30	0.5	2.09	0	90.00%	0.00	35.00%	0.00	188.31%	73.23%	0.000	0.000	0.000
N	3	30	0.5	2.09	0	85.00%	0.00	10.00%	0.00	177.84%	20.92%	0.000	0.000	0.000
N	4	30	0.5	2.09	2	85.00%	2.35	20.00%	11.76	177.84%	41.85%	0.956	1.125	5.623
N	5	30	0.5	2.09	1	90.00%	1.11	20.00%	5.56	188.31%	41.85%	0.478	0.531	2.655
N	6	30	0.5	2.09	0	90.00%	0.00	20.00%	0.00	188.31%	41.85%	0.000	0.000	0.000
				======	======	======	======	======	======	======	======	======	======	======
N	SEARCH			37.52	4	88.33%	4.53	34.17%	13.25	90.54%	37.75%	0.125	0.144	0.703
												======	======	======
	WEIGHTED AVERAGES					WEIGHTED AVERAGES			WEIGHTED AVERAGES					
					4	90.54%	4.42	37.75%	11.70					
	PER ACRE					PER ACRE			PER ACRE					
					0.107	90.54%	0.118	37.75%	0.312	POOR				
						TOTAL			TOTAL	COVERAGE				
				1043	111.21		122.83		325.38		3.60% (2.21%)			

REGIO	N		
COUN	12		
AVERA	0.125		
STD	0.283		
STDS	0.295		
STDS/	0.085		
CONFI	80.00%	90.00%	95.00%
"T"	1.363	1.796	2.201
T*STD	0.116	0.153	0.188
% OF	92.75%	122.22%	149.78%
UPPER	1.928	2.222	2.498
UPPER	0.241	0.278	0.313

APPENDIX B: OBSERVATION SUMMARY AND DATA REDUCTION - NORTHWEST REGION

REGION	SECTI	WIDTH FT	LENGT NM	AREA	OBSER	% OBSV-P	PROU	% HAR	TOTAL	%OBSV*AR	%HARD*A	OBSV/AR	PROUD/A	TOTAL/ARE
NW	1	30	0.5	2.09	1	90.00%	1.11	90.00%	1.23	188.31%	188.31%	0.478	0.531	0.590
NW	1	30	0.5	2.09	0	90.00%	0.00	80.00%	0.00	188.31%	167.38%	0.000	0.000	0.000
NW	1	30	0.5	2.09	0	90.00%	0.00	70.00%	0.00	188.31%	146.46%	0.000	0.000	0.000
NW	1	30	0.5	2.09	1	95.00%	1.05	40.00%	2.63	198.77%	83.69%	0.478	0.503	1.258
NW	1	30	0.5	2.09	3	90.00%	3.33	30.00%	11.11	188.31%	62.77%	1.434	1.593	5.311
NW	1	30	0.5	2.09	0	80.00%	0.00	15.00%	0.00	167.38%	31.38%	0.000	0.000	0.000
NW	2	30	0.5	2.09	1	90.00%	1.11	75.00%	1.48	188.31%	156.92%	0.478	0.531	0.708
NW	2	30	0.5	2.09	0	90.00%	0.00	65.00%	0.00	188.31%	136.00%	0.000	0.000	0.000
NW	2	30	0.5	2.09	0	90.00%	0.00	25.00%	0.00	188.31%	52.31%	0.000	0.000	0.000
NW	2	30	0.5	2.09	1	90.00%	1.11	10.00%	11.11	188.31%	20.92%	0.478	0.531	5.311
NW	3	30	0.5	2.09	1	90.00%	1.11	75.00%	1.48	188.31%	156.92%	0.478	0.531	0.708
NW	3	30	0.5	2.09	0	90.00%	0.00	65.00%	0.00	188.31%	136.00%	0.000	0.000	0.000
NW	3	30	0.5	2.09	1	95.00%	1.05	25.00%	4.21	198.77%	52.31%	0.478	0.503	2.012
NW	3	30	0.5	2.09	0	85.00%	0.00	10.00%	0.00	177.84%	20.92%	0.000	0.000	0.000
NW	4	30	0.5	2.09	0	90.00%	0.00	60.00%	0.00	188.31%	125.54%	0.000	0.000	0.000
NW	4	30	0.5	2.09	0	90.00%	0.00	50.00%	0.00	188.31%	104.61%	0.000	0.000	0.000
NW	4	30	0.5	2.09	0	95.00%	0.00	22.50%	0.00	198.77%	47.08%	0.000	0.000	0.000
NW	4	30	0.5	2.09	1	90.00%	1.11	12.50%	8.89	188.31%	26.15%	0.478	0.531	4.248
NW	5	30	0.5	2.09	0	50.00%	0.00	17.50%	0.00	104.61%	36.62%	0.000	0.000	0.000
NW	5	30	0.5	2.09	0	50.00%	0.00	5.00%	0.00	104.61%	10.46%	0.000	0.000	0.000
NW	6	30	0.5	2.09	0	60.00%	0.00	55.00%	0.00	125.54%	115.08%	0.000	0.000	0.000
NW	6	30	0.5	2.09	1	70.00%	1.43	5.00%	28.57	146.46%	10.46%	0.478	0.683	13.656
NW	7	30	0.5	2.09	0	80.00%	0.00	55.00%	0.00	167.38%	115.08%	0.000	0.000	0.000
NW	7	30	0.25	1.05	0	30.00%	0.00	5.00%	0.00	31.38%	5.23%	0.000	0.000	0.000
NW		SEARCH		49.17	11	81.67%	13.47	40.10%	33.59	82.77%	40.85%	0.219	0.247	1.408
		WEIGHTED AVERAGES				WEIGHTED AVERAGES			WEIGHTED AVERAGES					
					11	82.77%	13.29	40.85%	32.53					
		PER ACRE				PER ACRE			PER ACRE					
					0.224	82.77%	0.270	40.85%	0.662		POOR			
						TOTAL			TOTAL		COVERAGE			
				942	210.74		254.63		623.30		5.22%			

REGIO	NW		
COUNT	24		
AVERA	0.219		
STD	0.337		
STDS	0.345		
STDS/	0.070		
CONFI	80.00%	90.00%	95.00%
"T"	1.319	1.714	2.069
T*STD	0.093	0.121	0.146
% OF	42.36%	55.04%	66.44%
UPPER	1.424	1.550	1.664
UPPER	0.312	0.340	0.365

APPENDIX B: OBSERVATION SUMMARY AND DATA REDUCTION - WEST REGION

REGION	SECTIO	WIDTH FT	LENGT NM	AREA	OBSERV	% OBSV-P	PROUD	% HAR	TOTAL	%OBSV*ARE	%HARD*AR	OBSV/AR	PROUD/AR	TOTAL/AREA
W	1	30	0.5	2.09	5	90.00%	5.56	90.00%	6.17	188.31%	188.31%	2.390	2.655	2.950
W	1	30	0.5	2.09	4	90.00%	4.44	90.00%	4.94	188.31%	188.31%	1.912	2.124	2.360
W	1	30	0.5	2.09	5	85.00%	5.88	85.00%	6.92	177.84%	177.84%	2.390	2.811	3.308
W	1	30	0.5	2.09	2	85.00%	2.35	80.00%	2.94	177.84%	167.38%	0.956	1.125	1.406
W	1	30	0.5	2.09	4	85.00%	4.71	57.50%	8.18	177.84%	120.31%	1.912	2.249	3.912
W	1			320.00	0	95.00%	0.00	80.00%	0.00	30400.00%	25600.00%	0.000	0.000	0.000
W	2	30	0.5	2.09	2	90.00%	2.22	90.00%	2.47	188.31%	188.31%	0.956	1.062	1.180
W	2	30	0.5	2.09	4	90.00%	4.44	90.00%	4.94	188.31%	188.31%	1.912	2.124	2.360
W	2	30	0.5	2.09	2	85.00%	2.35	85.00%	2.77	177.84%	177.84%	0.956	1.125	1.323
W	2	30	0.5	2.09	1	85.00%	1.18	57.50%	2.05	177.84%	120.31%	0.478	0.562	0.978
W	3	30	0.5	2.09	0	90.00%	0.00	40.00%	0.00	188.31%	83.69%	0.000	0.000	0.000
W	3	30	0.5	2.09	0	90.00%	0.00	40.00%	0.00	188.31%	83.69%	0.000	0.000	0.000
W	3	30	0.5	2.09	0	85.00%	0.00	40.00%	0.00	177.84%	83.69%	0.000	0.000	0.000
W	3	30	0.5	2.09	1	85.00%	1.18	30.00%	3.92	177.84%	62.77%	0.478	0.562	1.874
W	4	30	0.5	2.09	1	90.00%	1.11	40.00%	2.78	188.31%	83.69%	0.478	0.531	1.328
W	4	30	0.5	2.09	0	90.00%	0.00	40.00%	0.00	188.31%	83.69%	0.000	0.000	0.000
W	4	30	0.5	2.09	0	85.00%	0.00	30.00%	0.00	177.84%	62.77%	0.000	0.000	0.000
W	5	30	0.5	2.09	1	90.00%	1.11	40.00%	2.78	188.31%	83.69%	0.478	0.531	1.328
W	5	30	0.5	2.09	0	90.00%	0.00	40.00%	0.00	188.31%	83.69%	0.000	0.000	0.000
W	5	30	0.5	2.09	0	85.00%	0.00	30.00%	0.00	177.84%	62.77%	0.000	0.000	0.000
W	SEARCH			359.75	32	88.00%	36.36	58.75%	61.90	94.19%	77.53%	0.765	0.873	1.215
	WEIGHTED AVERAGES					WEIGHTED AVERAGES			WEIGHTED AVERAGES					
					32	94.19%	33.98	77.53%	43.82					
	PER ACRE					PER ACRE			PER ACRE					
					0.089	94.19%	0.094	77.53%	0.122					
						TOTAL			TOTAL	COVERAGE				
				2276	202.45		214.95		277.25		15.81% (1.75%)			

REGIO	W		
COUNT	20		
AVERA	0.765		
STD	0.847		
STDS	0.869		
STDS/R	0.194		
CONFI	80.00%	90.00%	95.00%
"T"	1.328	1.729	2.093
T*STDS	0.258	0.336	0.407
% OF M	33.74%	43.93%	53.18%
UPPER	1.337	1.439	1.532
UPPER	1.023	1.101	1.171

APPENDIX C:

Magnetometer Field Survey: Kaho'olawe Island, 24-27 June 1993

After consideration of many magnetometers, SCI decided to rent a model G-76 proton precession magnetometer system from EG&G Geometrics of Sunnyvale, CA. Lease of this system, which incorporates a state of the art sensor, a new digital data transmission system, an 80386-based PC for processing and logging and a dot-matrix printer for plotting, was more cost-effective for the present short survey duration than the purchase of less costly competitor systems. Based upon the results of the field survey summarized below, SCI recommends the use of a system equal to or better than the Geometrics G-76.

An altitude measurement system was unavailable for the preliminary survey, though the magnetometer manufacturer is presently developing one and expects to have it available in the near future. For the preliminary survey, the fish-finding fathometer on the vessel was used to attempt to follow specific contours of bottom depth. This worked well in areas of smooth bottom, but was much less successful when the bottom contours were irregular.

Initial magnetometer runs were invalidatd by mechanical problems in the sensor housing of the magnetometer. After several discussions (via cellular phone) with the factory technician, it was determined that factory check out of the system had been incomplete, resulting in leakage of the hydrocarbon oil sensor fluid and subsequent partial seawater flooding of the sensor. A field repair was successfully performed. Following system repair, calibration runs were conducted between Hana Kanaia and the point south of Honukanaenae. The magnetic field readings were consistently between 32,000 and 36,000 nT, as expected. [1] The readings fluctuated more than expected however, varying more than 1,000 nT over horizontal distances of a few hundred meters. To verify correct operation of the system, we conducted a test in which the sensor was towed for about one mile from the point south of Honukanaenae toward Hana Kanaia, then towed back and the tow was repeated over the same track. Though it was not immediately obvious from the confused field records, post-analysis later in the day produced the graphs shown in Figure C1, which clearly demonstrate that the field measurements were internally consistent. The extremely high variability of the natural field over short distance scales is probably

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[1]Magnetic Field Units: The traditional unit of magnetic field strength is the Oersted, approximately equal to the maximum of the earth's field. Magnetic anomalies have been traditionally measured in "gammas", where 1 gamma is 10^{-5} Oersted. Modern SI units have defined the "Tesla" which is 10^{4} Oersted, so that 1 gamma is equivalent to 1 nanotesla (1 nT).

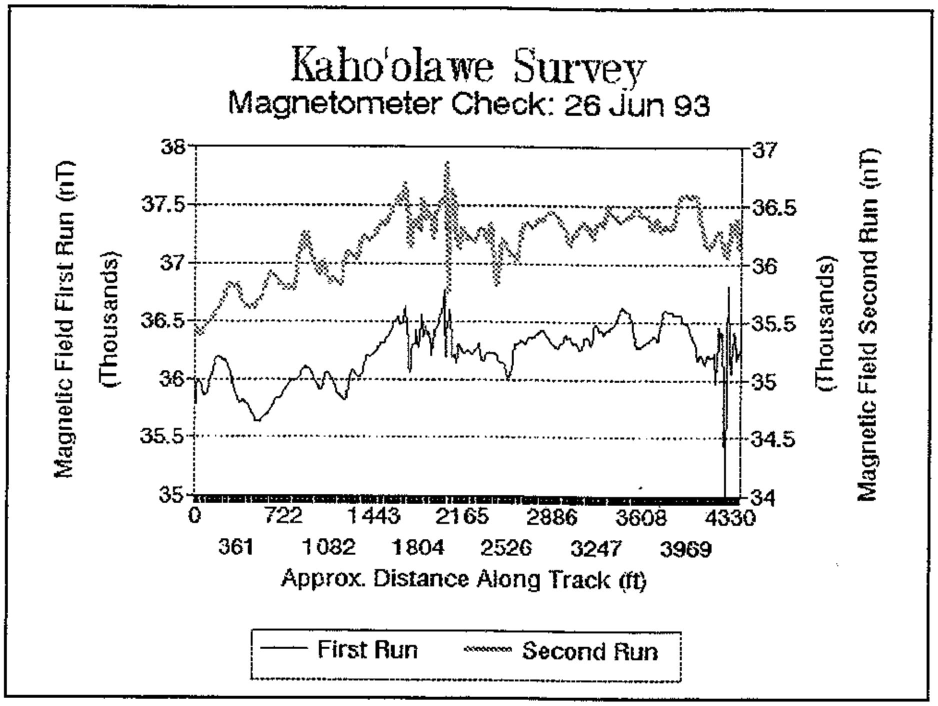


Figure C1. Magnetometer Test on 26 June 1993 in the vicinity of Hana Kanaia.

caused by varying iron composition of the lava flows which make up the substratum. Such high natural variability will make it extremely difficult to detect UXO in this area.

The remainder of 26 June was spent on diver surveys of the South Coast of Kaho'olawe, and there was no opportunity to collect further magnetometer data. Following diver and video surveys on the morning of 27 June, a magnetometer survey was conducted following the 10 fm (60 ft) contour along the north coast of the island. Magnetometer runs were conducted from Hana Kanaia in the SW region, clockwise to Lae o Kukui in the NE region. The complete record (Figure C2) extends from off Lae o Keawaikahiki to beyond Papakaiki. This and the following figures present time of measurement on the abscissa since precise navigation was unavailable as discussed above. The survey speed was generally 3-5 knots, and the approximate horizontal scale for the measurements can be obtained from Figure C3, which gives distance travelled vs time for this speed range. Figures C4 through C10 present the data in 1/2 hour increments, each approximately 1 mile of track.

This survey was conducted to determine the variability of the natural magnetic field in the area, since it was recognized that UXO detection by magnetometer would be extremely difficult if all areas showed the high variability found off Hana Kanaia. As discussed above, there was insufficient time to perform the detailed type of survey which will be required for detection and classification of underwater UXO, so this more general survey was deemed to be the most appropriate use of the magnetometer time.

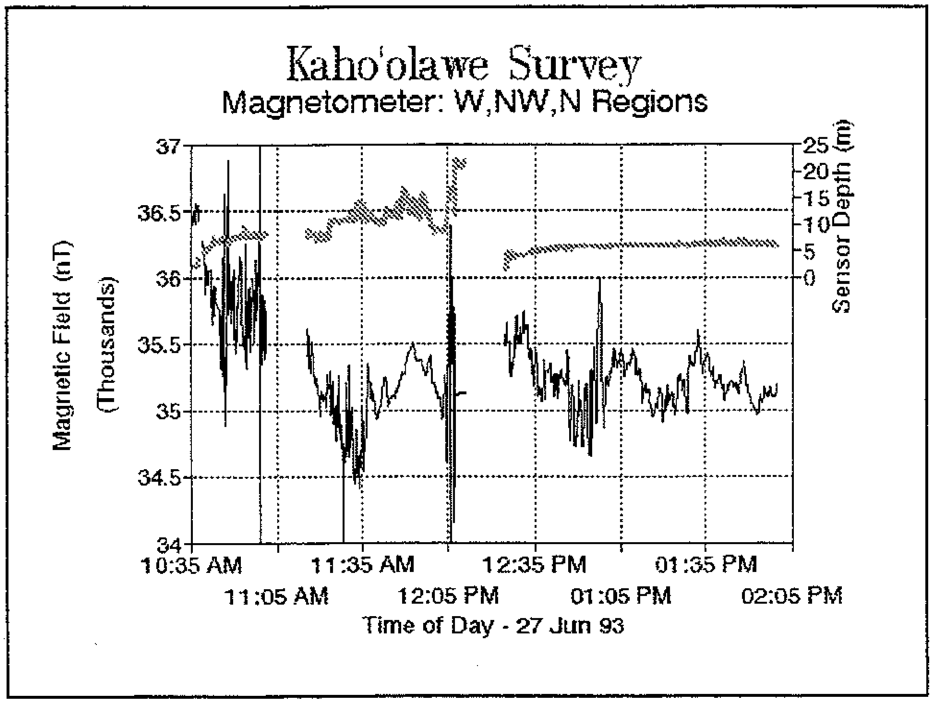


Figure C2. All magnetic data collected on 27 June 1993 near Hana Kanaia.

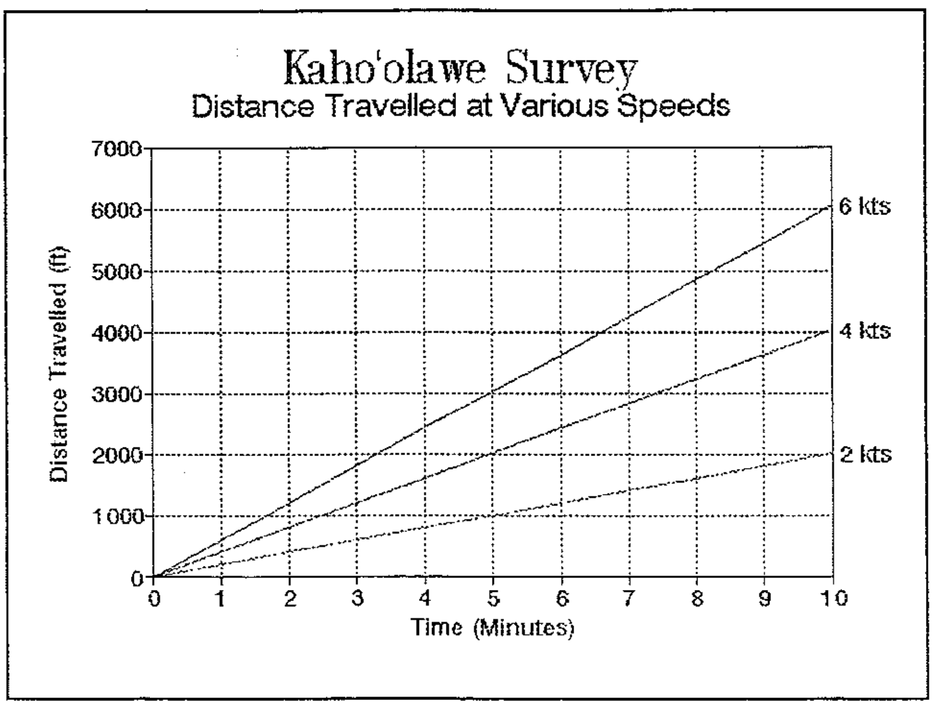


Figure C3. Distance travelled in feet vs time in minutes for survey speeds from 2 knots to 6 knots. The preliminary Kaho'olawe survey was conducted at speeds between 3 and 5 knots.

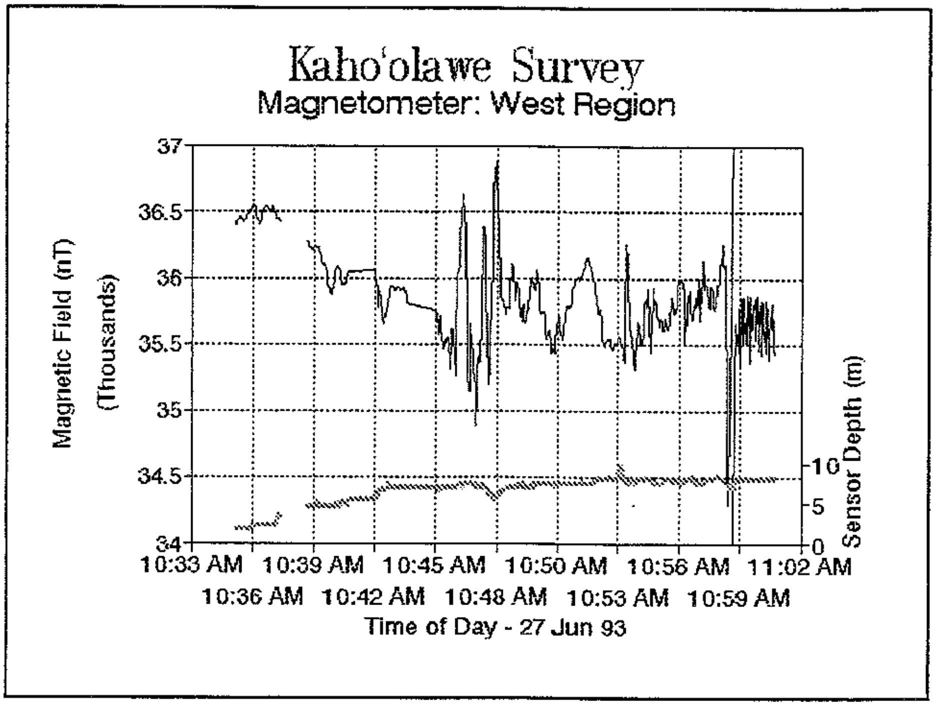


Figure C4. First part of the magnetometer record of 27 June, covering the coastline from near Lae o Kealaikahiki toward Honokoa.

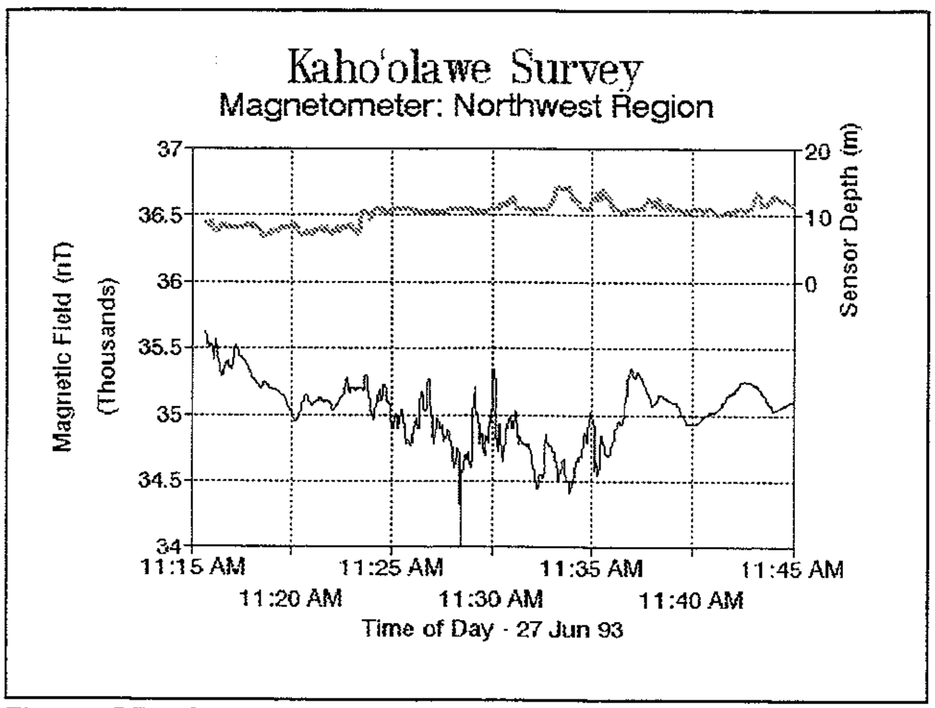


Figure C5. Second part of the magnetometer record of 27 June, covering the coastline from west of Honokoa past Honokoa towards Ahupu. Sensor depth is plotted (light line) above the magnetometer curve.

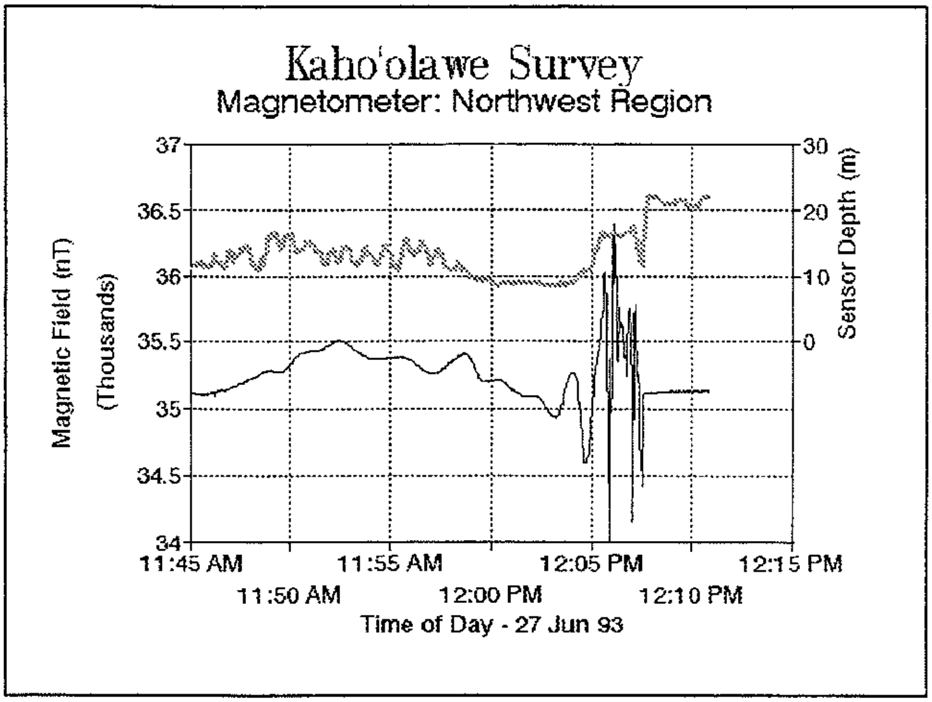


Figure C6. Third part of the magnetometer record of 27 June, covering the coastline from east of Honokoa to where the magnetometer snagged the bottom off Makaalae. Sensor depth is plotted (light line) above the magnetometer curve.

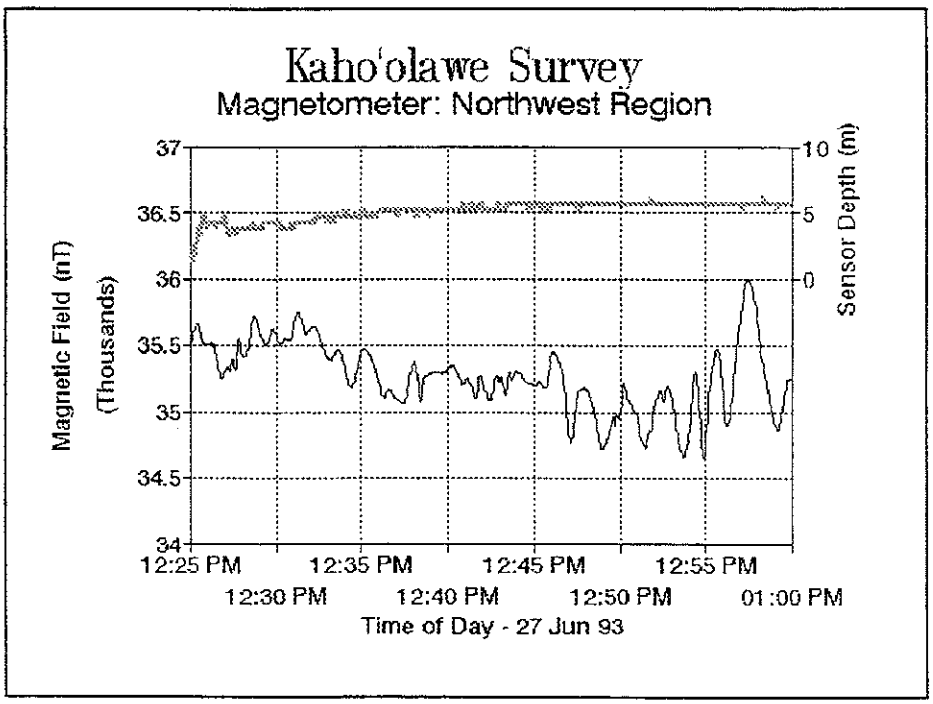


Figure C7. Fourth part of the magnetometer record of 27 June, covering the coastline from Makaalae to Ahupu. Sensor depth is plotted above the magnetometer curve.

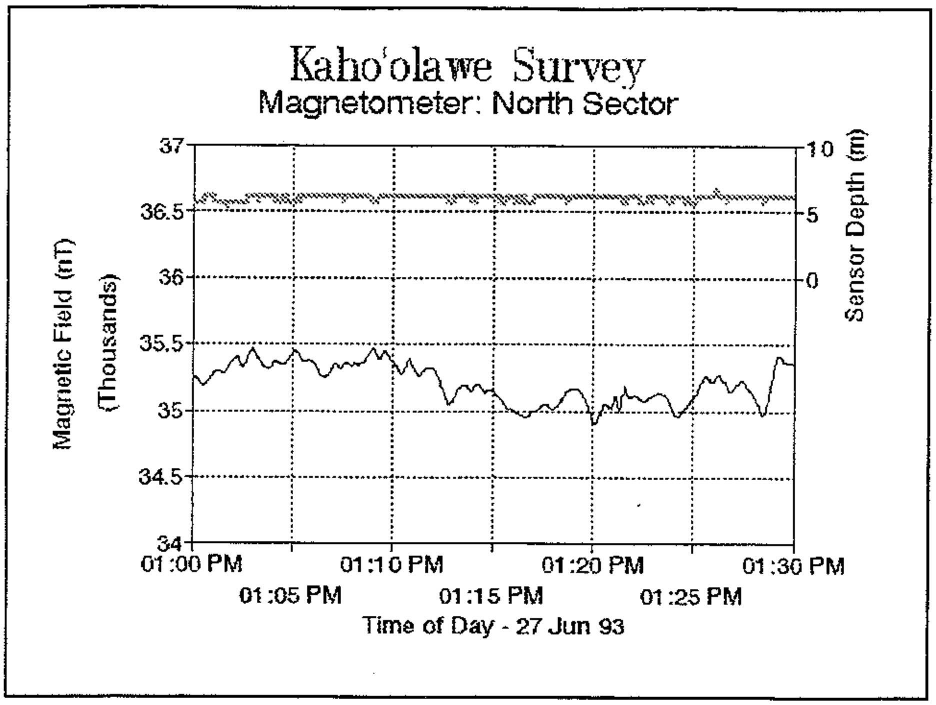


Figure C8. Fifth part of the magnetometer record of 27 June, covering the coastline from Ahupu to the point just west of Lae Hilu ula. Sensor depth is plotted (light line) above the magnetometer curve.

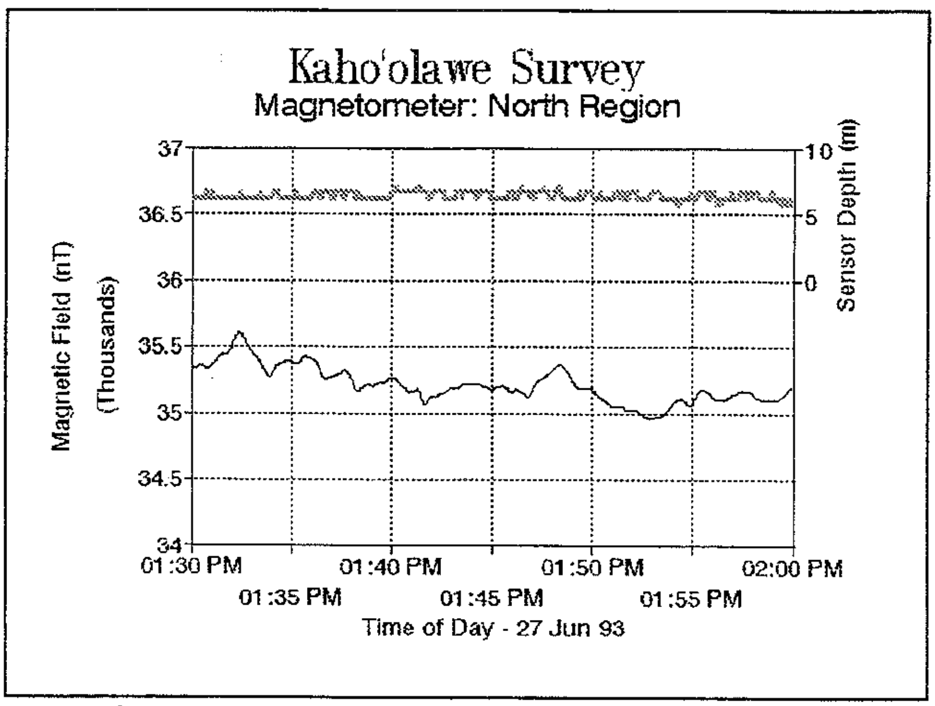


Figure C9. Sixth and last part of the magnetometer record of 27 June, covering the coastline from the point just west of Lae Hilu ula to just past Waaiki Point. Sensor depth is plotted (light line) above the magnetometer curve.

Magnetometer Survey Results

As can be clearly seen in Figures C1, C2 and C4-C10, there are great differences in the natural variability of the magnetic field for different sectors surveyed around Kaho'olawe. These differences significantly affect the ability to detect underwater objects.

It is difficult to detect possible ordnance from the magnetic record in areas where the earth's field exhibits large horizontal gradients, such as around Hana Kanaia (Figure C1), the area surveyed between 10:45 and 10:58 (Figure C4), that between 11:25 and 11:35 (Figure C5), and that between 12:46 and 1:00 PM (Figure C7) on 27 June. It is unlikely that the large fluctuations found at the middle of the record of Figure C1 are all due to UXO, since they are clearly spread over 200 meters or more. The same can be said for the large variations near the end of the record of Figure C1, and those between 10:45 and 10:48 in Figure C4. These large fluctuations might indeed be caused by foreign iron masses, but the distance scale of the anomalies (~30 m) leaves open the possibility that they were instead caused by contrasting iron content in neighboring lava flows. It is nevertheless true that detailed investigation of the area around those fluctuations is warranted. If a visual survey revealed nothing, then the contours provided by a more detailed magnetic survey might indicate the likelihood of buried ordnance. As noted above, nothing definitive can be said based on the measurements alone.

Even when the earth field gradients are large, some anomalies stand out from the record. A very large signature occurs in the record at 11:28 AM. Note that the plots in the figures include a point every two seconds, so this and other anomalies are not isolated data points but represent major excursions of the record. At 11:28, Figure C5 shows a very large negative deviation of the total magnetic field. The sensor depth remained constant at about 10-11 meters during this time. This anomaly was most likely caused by a large iron object located to one side of the vessel track. The magnetic "south pole" of the object was pointed toward the sensor, so that the total measured field (representing the sum of the earth's field and that of the object) is much less here than the ambient earth's field. This anomaly of about 600 nT is very obvious even though the natural field is varying hundreds of nT over distances of tens of meters.

Even though not as large in amplitude, other anomalies stand out in the record portions which exhibit high natural variability. These are distinguishable by the very short wavelength which they exhibit. It seems unlikely that "blips" in the record such as those at 10:45, 10:47 and 10:52 (Figure C4) are caused by lava flow variability. They definitely warrant further investigation as possible sites of unnatural iron concentration.

If the natural field is constant or changing smoothly and relatively slowly, then the anomaly or signature caused by an iron object will stand out more clearly from the record. Much smaller anomalies will be discernible, even in a single-track record. Such signatures can be seen at several points in the record shown in Figures C4-C10. Good examples can be found at 11:46.5 and 1203.5 in Figure C6.

Table C1 summarizes the times of measurements which suggest the magnetic signature of iron objects. Since we do not have precise navigation for this survey, There is little point in following up of on any of these specific measurements. The records do show, however, that a single pass with a magnetometer can provide information on sites which should be further investigated for the presence of UXO.

Table C1. Magnetometer Detections

Date	Time/ Dist*	Region	Figure	Area: Rough /Smooth	Amplitude (Nt)	Time Width (min)	Probability (H,M,L)	Fish Depth (m)
26 Jun	850ft	W	A1	Rough	50	1	M	10
	2000	W	A1	Rough	480	1.5	M	10
	4325	W	A1	Rough	1700	1.5	M	10
27 Jun	10:45	W	A4	Rough	120	1	M	9
	10:47	W	A4	Rough	50	.7	M	9
	10:52	W	A4	Rough	30	.5	M	10
	10:54	W	A4	Rough	30	.4	M	10
	11:26	NW	A5	Rough	70	.4	M	11
	11:28	NW	A5	Rough	700	.2	H	11
	11:32	NW	A5	Rough	50	.3	M	11
	11:46	NW	A6	Smooth	30	.2	H	11
	12:03.5	NW	A6	Smooth	40	.3	H	9
	12:50	NW	A7	Rough	80	1	H	6
	12:53	NW	A7	Rough	100	1.5	M	6
	13:20	N	A8	Rough	20	.1	M	6.5
	13:58	N	A9	Smooth	10	.3	L	6.5

* Time for all but 26 June, when distances, as shown in Figure C1, are given.

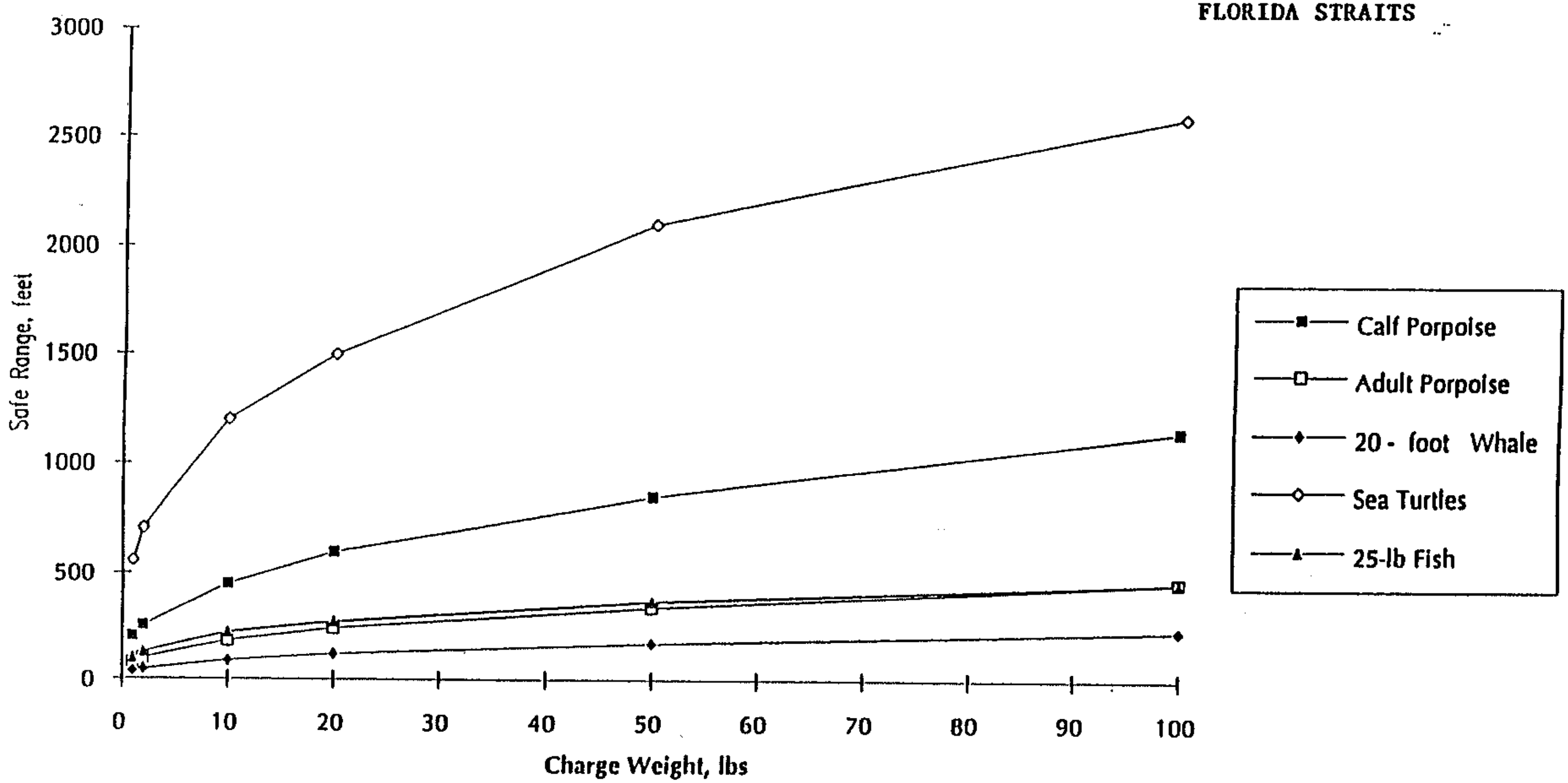
Conclusions

The results of SCI's preliminary survey suggest that a magnetometer survey might provide a cost-effective way to locate sites of UXO around Kaho'olawe. Based upon these findings, SCI recommends a comprehensive magnetic survey using a magnetometer similar to the EG&G Geotech Model G-76 as the first component of the detection process. Using an appropriate survey vessel with precision navigation and good control at low speeds and a controllable depressor system with feedback from an altimeter to maintain sensor altitude, single passes around the circumference of the island along nominal contours of, say 30 feet, 60 feet and 90 feet will provide a catalog of sites appropriate for further investigation. In areas where the offshore slope is more gradual, such as much of the North coast, intermediate lines at approximately 15 ft contour intervals will be needed to ensure better areal coverage.

Careful analysis of the records from the initial magnetometer survey will yield a catalog of sites for further investigation. If, as will probably be the case, these sites are too numerous for multiple sensor detailed reconnaissance, initial surveys with divers could be followed up with detailed magnetometer contouring in those areas where the divers find nothing. These contours will provide clues about the size and depth of buried items.

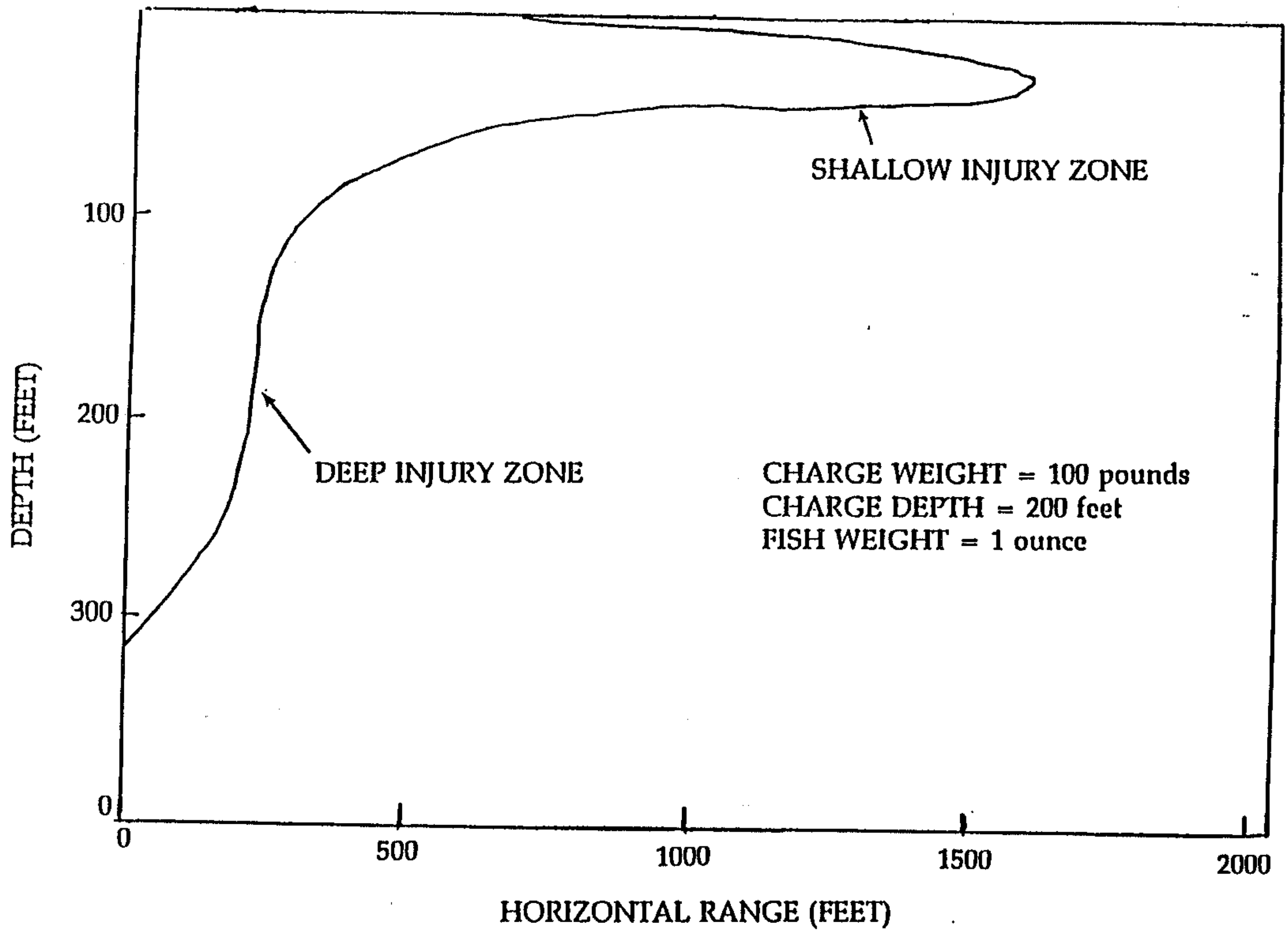
APPENDIX D

ENVIRONMENTAL ASSESSMENT OF
SMALL SCALE NAVY UNDERWATER
EXPLOSIVE TESTING IN THE
FLORIDA STRAITS



SAFE RANGES FOR SEA MAMMALS, SEA TURTLES,
AND FISH (@ 500-FOOT CHARGE DEPTH)

SOURCE: Young, G.A. 1992



90 PERCENT FISH SURVIVABILITY CONTOUR

D - 2 Source: Young 1992

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