# EVALUATION OF A CONTAINMENT BARRIER FOR HAZARDOUS MATERIAL SPILLS IN WATERCOURSES

by

Thomas N. Blockwick
Samson Ocean Systems, Inc.
99 High Street
Boston, Massachusetts 02110

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Project Officer

Ira Wilder
Oil and Hazardous Materials Spill Branch
Municipal Environmental Research Laboratory (Cincinnati)
U.S. Environmental Protection Agency
Edison, New Jersey 08837

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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## FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communications link between the researcher and the user community.

Development of methods, such as the Hazardous Material Barrier described in this report, can help in the containment or confinement of spills or leaks of hazardous materials in our waterways and prevent the dispersion of potentially dangerous materials. Often, such confinement is the vital first step before the manpower and equipment for cleanup and decontamination can be brought to bear on an incident to protect the environment.

Francis T. Mayo
Director
Municipal Environmental
Research Laboratory

# PREFACE

Early in the Agency's history, growing concern over spills of hazardous materials, particularly those which impact on our nation's waterways, led the USEPA to recognize a need for quick containment of spills as a first step in the clean-up process. The Hazardous Material Barrier (HMB) evolved as one possible answer.

This study, conducted during the early 1970's, suggested that a properly designed barrier system could contain spills and leaks that were not rapidly dispersed into the water environment. This would include releases of concentrated insoluble hazardous substances that pool on or near the bottoms of watercourses. However, the studies also demonstrated that the HMB had serious shortcomings, the greatest being its sensitivity to currents, the time required for deployment, and weight-related handling difficulties. Rapid technological advancements in plastics and their fabrication, coupled with the experiences gained from this study, may make it possible, today, to construct a barrier that can be deployed more rapidly and with less difficulty.

Even though this report is being issued several years after project completion, information on the study has been presented at the 1972 National Conference on Control of Hazardous Materials Spills and technical advice has been provided on this topic to EPA Regions making inquires. It is hoped that the release of the report will stimulate those in the user community that may want to further development of this concept.

## ABSTRACT

Field tests were carried out during 1976 with an improved barrier for the containment of hazardous material spills and leaks in waterways. The improvements were based on the results of design, fabrication, and field tests carried out in 1971 and 1972.

As currently configured, the Hazardous Material Barrier (HMB) consists of a reinforced plastic film that can be used to encircle a spill or a leaking vehicle, such as might result from a transportation accident. An airfilled bladder provides flotation to keep the upper edge of the barrier on the surface of the waterway while a liquid-filled bladder rests on the bottom and seals the circumference, thus containing the spill in a minimum volume of water and segregating it from the forces which tend to disperse it.

While the current version of the HMB and its deployment still require further improvements before the system could be considered practical for field use, the trials reported at this time suggest that such a "curtain" could be useful in containing a hazardous material spill or leak. The most serious drawback of the HMB is its inability to retain its shape and, therefore, perform its function when the current of the waterway exceeds 1 knot.

This report was submitted in fulfillment of Contracts No. 68-01-0103 and 68-03-2168 by Ocean Systems, Inc. under the sponsorship of the U.S. Environmental Protection Agency and covers the period September 1971 to July 1977. Work was completed as of July 1977.

CONTENTS

FIGURES

## TABLES

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## SECTION 1

## INTRODUCTION

Despite a growing awareness of the dangers of hazardous materials, accidental spills on land and into the nation's waterways still occur at an alarming rate. Depending on the character of the spilled material and the nature of the spill site, these incidents can present varying degrees of hazard to the human and aquatic populations involved.

Although each incident requires specific countermeasures, certain general requirements apply. For spills into waterways, countermeasures must be effective in flowing streams, impoundments, estuaries, and the open sea. They should be capable of rapid implementation in both congested and remote areas. The countermeasure also should use a minimum of auxiliary equipment, be safe to handle by semi-trained personnel, and should cause no secondary damage to the environment.

A number of chemical, biological, and physical countermeasures for dealing with spills are in use or have been tried with varying success. A review of many of these methods indicated that physical containment of the spill often is a vital first step in improving the potential for coping with spills in waterways. Physical containment, by reducing dilution and dispersion of the material, minimizes the volume of contaminated water that must be treated and extends the time period over which the spill can be treated. As a result, the ultimate treatment or disposal of the contained substance often can be accomplished more safely and more effectively.

Based on these observations, it was proposed that a lightweight, rapidly deployable, physical barrier system would be useful for a wide variety of spilled substances. In June 1971, Ocean Systems, Inc. was awarded a contract (68-01-0103) by the U.S. Environmental Protection Agency (EPA) for the construction and testing of a prototype containment barrier for hazardous material spills. Such a prototype containment system, featuring a plastic film barrier, was designed, constructed, and tested during 1971 and 1972.

Following the series of tests in 1971 and 1972, recommendations were made for a new, strengthened Hazardous Material Barrier (HMB). This second generation prototype was constructed and subsequently tested in June and July of 1976, under a second contract, 68-03-2168. Results of both sets of tests and recommendations for an operational version are presented herein.

## SECTION 2

## CONCLUSIONS

As a result of the field tests conducted during the 1976 test program, the following conclusions have been reached concerning the barrier system for containment of hazardous material spills:

1. The barrier system can be a viable countermeasure against spilled hazardous materials, although some changes are still required for an optimized operational system.

2. Deployment of the Hazardous Material Barrier (HMB) can be accomplished in time to contain slow spills or leaks or where a significant amount of pollutant remains at the source 8 to 12 hr after the barrier arrives at the scene.

3. Use of the barrier may not be feasible in all situations. The On-Scene Coordinator must determine the feasibility of deploying the system to combat an actual spill.

4. The barrier can be effective in average currents up to one knot under good weather conditions.

5. Deployment of the barrier in currents faster than one knot is not recommended. Retention of the desired circular shape cannot be assured at higher currents; the barrier may lose its shape and tend to close in on itself on the surface, while the lower seal may tend to rise.

6. The self-embedment anchoring system used to moor the HMB is extremely effective. Mushroom anchors (an option) present problems.

7. Better deployment of the HMB can be achieved by using an improved mechanical handling system, a trained crew and proper support, including divers and suitable surface craft. Deployment of the barrier by an untrained crew is difficult even under the best conditions, but a marked improvement is achieved with a single practice deployment.

8. The pull-down system for deployment works well, but a more efficient system is needed to move the barrier into the water.

9. The field tests of the improved prototype have indicated specific

areas where design changes would improve deployment of an operational barrier.

10. Tidal flushing can be an important factor when using the barrier and must be considered when using the HMB.

## SECTION 3

## RECOMMENDATIONS

We strongly recommend that the HMB system be made fully operational, after incorporating the following changes in design and deployment procedures:

1. Construct a new barrier with the following changes:

   a. If feasible, use a zipper-type mechanism to attach the two ends of the curtain. Retain the existing lacing and grommet system as a backup.

   b. Change the air bladder relief valve specifications to 1.0 or 1.5 psi over-pressure and use coarser threading on the valves. Investigate the use of relief valves such as those on divers' suits.

   c. Use a non-kinking hose to insure that no kinking of air inflation hoses can occur, particularly near the inlet to the air bladder.

   d. Insure more quality control over electronic welding of seams, or use stitched seams.

   e. Design a method and system for evacuation of the bottom seal bladder and bleed-off of any trapped air. Investigate the feasibility of using a zippered or double Velcro closure for these purposes.

   f. Use two inlets to fill the bottom seal bladder instead of one; insure that no kinking of hoses can occur.

   g. Use stronger or doubled material in the bottom seal bladder, where most abrasion occurs.

   h. Strengthen the barrier at other critical points as indicated by the tests.

2. Design and construct a new handling and winch system to move the barrier from land to water and back.

3. Implement changes in deployment techniques as follows:

a. Use divers when possible. However, the use of divers should not be designed into the system.

b. Remove flotation before pull-down of each section.

c. Inflate air bladder initially using a bank of compressed air tanks and top-off using a compressor.

d. If feasible, fill bottom seal bladder with a dense slurry rather than water.

e. Use mechanical assistance and handling systems to maximum advantage.

f. Minimize towing of the HMB in deployment and recovery operations.

4. Develop mechanical aids to eliminate or reduce the need for divers in deployment and recovery of the barrier.

5. Do not deploy the barrier in currents exceeding one knot.

SECTION 4

# BARRIER SYSTEM DEVELOPMENT

## DESIGN APPROACH

In accordance with the Environmental Protection Agency's general objectives for the design of equipment for controlling spills of hazardous materials (ref. FWQA Request for Proposal WA71-513), Ocean Systems, Inc. used the following guidelines during development of the containment system for use in watercourses. The system should:

- Be effective in flowing streams, impoundments, estuaries, and in moderate seas.
- Be capable of rapid deployment in both congested and remote areas.
- Be light in weight and easily transported.
- Require a minimum of auxiliary equipment.
- Be constructed of state-of-the-art materials and components and should be reasonable in first cost.
- Be capable of being deployed by a minimum number of trained personnel.
- Have a long shelf life with little or no maintenance.
- Be ecologically acceptable and should not cause any secondary damage to the environment.

To be effective against soluble substances, a containment barrier should completely prevent escape of polluting materials from the contained mass of water. This means that the bottom of the barrier must seal against the bottom of the watercourse and that the top of the barrier must be supported above the water surface. A flexible fabric barrier with inflatable support flotation and bottom seal was the only concept for a containment barrier that was fully consistent with the guidelines presented above.

Because the barrier had to be designed for use in flowing water, an anchoring scheme that provides strong vertical holding power for restraining the barrier and holding it tightly to the bottom of the watercourse was required. Explosive embedment anchors were considered to be the only type of anchors that could meet these two requirements and still satisfy the general guidelines for the system.

To deploy the system effectively without divers and within the restraints of the design guidelines, a unique deployment scheme was devised. Very briefly, it consists of the following steps:

- Package the barrier by folding it vertically and binding it with tape of a known breaking strength.
- Place the packaged barrier in a temporary moor around the spill source while it is still floating on the water surface.
- Install explosive anchors using the floating barrier as a template for accurate placement of the anchors.
- Using special one-way gripping devices, pull the barrier down the explosive anchor mooring pendants to the bottom of the watercourse.
- Inflate the air bladders from the surface through a hose. This will cause the tape bindings to break, and the top of the barrier will rise back to the water surface.
- Fill the bottom seal to complete deployment of the barrier.

## DETAILED DESCRIPTION OF SYSTEM

The containment barrier system may be conveniently divided into three subsystems. The three subsystems are:

- The barrier subsystem;
- The anchor subsystem;
- The deployment subsystem.

The design, construction, and development testing of each of these subsystems are described in the following paragraphs.

### Barrier Subsystem

The barrier is a highly flexible, fiber-reinforced plastic curtain that can be deployed around a spill source. Incorporated into the barrier is an air-inflated flotation collar that supports the barrier, and a liquid-filled bladder that seals the bottom of the barrier to the bottom of the waterway in which the barrier is deployed.

### Anchor Subsystem

Five explosive embedment anchors manufactured by EDO Western Corporation are used for mooring the barrier. Explosive embedment anchors (Figure 1) were selected because of their very high holding-power-to-weight ratio, and their ability to be installed rapidly in comparison to alternate anchoring systems. The anchor assembly weighs approximately 100 lb in the ready-to-fire configuration. The anchor itself weighs only 25 lb and has a confirmed vertical pull-out force of at least 10,000 lb for sand and mud installations. The same anchor system can be used with a different anchor point for rock installation.

Two methods for firing the anchor are available. One method is the remote electrical method described here and the other is a bottom contact method. The electrical method was selected because it was believed that the anchors could be placed more accurately using this method. For instance, if the anchor is not set on the bottom initially, it can be picked up and relocated before firing. The contact-type anchor fires immediately on touching the bottom. Deadweight or other types of anchors can be used as an emergency anchoring system, if the current velocity in the watercourse is low.

Deployment Subsystem

This subsystem includes special devices for pulling the barrier to the bottom and mooring it to the anchor pendants, equipment for filling the air and water bladders, vessel(s) for deploying the barrier, and marker buoys and anchors for temporarily mooring the barrier.

Figure 2 illustrates the gripper devices used to pull the barrier to the bottom and moor the barrier to the anchor pendant. The pull-down grip is first put on the anchor pendant. This grip is permitted to free-fall or is lowered down the anchor pendant until it reaches bottom. Both ends of the pull-down line are maintained on the surface during this procedure. When the pull-down grip is on the bottom, the end of the pull-down line is attached to a bail located on the mooring grip, and the top of the mooring grip is attached to an anchor ring on the barrier. When the free end of the pull-down line is pulled on, the barrier will move down the anchor pendant. The grips are designed to slide when moved in one direction on a cable and to be self-activating when pulled in the other direction.

The mooring grip has a rated strength of 15,000 lb. To check this figure and assure that the grip would function properly on the particular type of wire rope used for the anchor pendant, a structural test was performed. The grip was installed on a length of the wire rope and was put on a hydraulic tensile testing machine. The machine loaded the grip and wire rope with a force of 15,000 lb without any malfunction or apparent structural damage to the grip or wire rope.

Five lightweight-type (LWT) anchors are used to moor the barrier in a temporary position while the explosive anchors are installed. Each temporary mooring line to be used with these anchors should be at least 100 ft long so that the anchor can develop full holding power. The preferred line for this use is 3/8-in. diameter, braided nylon line. The braided line is much easier to work with and is stronger than twisted line.

Five buoys of at least 50 lb buoyancy are required for supporting the

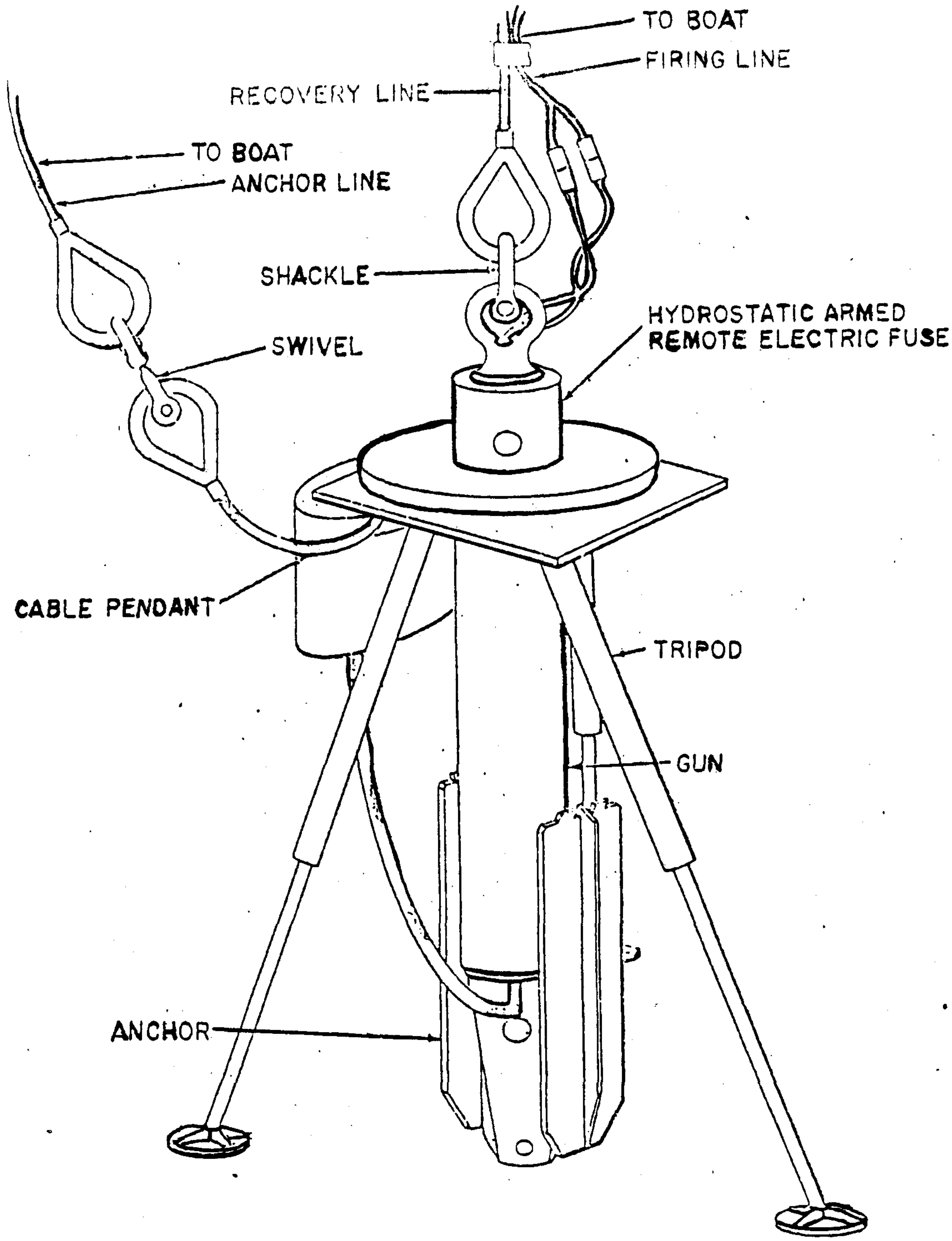


Figure 1. Vertohold embedment anchor-remote (electric) placement.

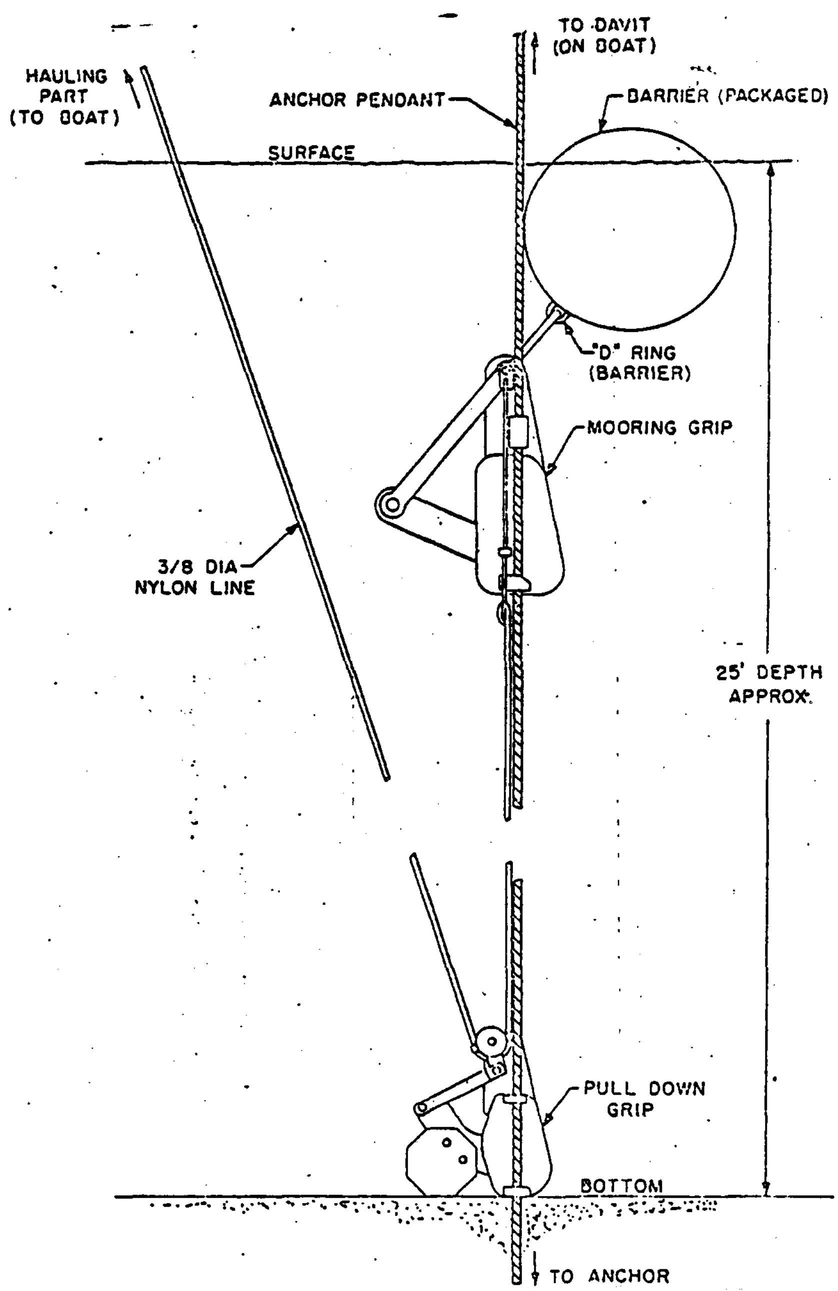


Figure 2. Pull-down schematic.

anchor pendants and pull-down devices during deployment operations. These buoys should have a 3-ft line with snap hooks attached so that they can be easily installed on the pendants. In addition, five smaller buoys of about 20 lb buoyancy are required to support the five ends of the pull-down lines.

A small boat equipped with an outboard motor is required for installation of the barrier system. This boat should have at least a 1000 lb rated load capacity and should be equipped with an outboard motor of at least 5 hp if used to deploy the barrier in still water. If the barrier is to be deployed in a watercourse where there is a current, a larger boat is required for towing the barrier. Preferably, two boats should be available for deployment of the barrier system.

The boat should be fitted with a device capable of lifting a 200 to 300 lb load to a height of 5 ft and moving it over the bow of the boat. This device must be equipped with a hand winch with at least 50 ft of line for lowering the anchor to the bottom. An unmodified grip of the size used for the pull-down grip should be available for attachment to the end of the winch line so that the anchor pendant can be gripped and pulled taut.

The air compressor/water pump unit required for inflation of the barrier flotation collar and filling of the bladder seal is powered by a 6.5 hp gasoline engine. It includes a direct-coupled rotary air pump with a rated delivery of 14 SCFM at 10 psig and a clutch-coupled water pump with a rated delivery of 125 gpm at a 20-ft head. Shop tests of the unit found that the delivered volumes were 10 SCFM at 10 psig for the air compressor and 100 gpm at a 20-ft head for the water pump, which were the original specifications.

<u>Bear Lake Test</u>

Preliminary tests were conducted in September 1971 at Bear Lake to introduce and train Ocean System, Inc. personnel in the correct assembly and field use of the explosive embedment anchors and to test the pull-down device that was under development at the time. Two Ocean Systems, Inc. personnel and two EDO Western Corporation personnel participated in the test.

## SECTION 5

## PROTOTYPE FIELD TESTS

Three field tests of the prototype barrier were conducted between October 1, 1971 and April 30, 1972. The first test was conducted in a lake in West Virginia. The second test was conducted in the lower Potomac River in Virginia; however, adverse weather forced cancellation of this test before it could be completed and, as a result, a third test of the barrier was conducted in Florida.

### WEST VIRGINIA FIELD TEST

A small private lake located at Sugar Grove, West Virginia, was selected as the test site at which to evaluate the barrier and deployment techniques under still water conditions. It was necessary to use this lake, which is approximately 150 miles from Ocean Systems' Reston, Virginia facility, because of problems in obtaining permission to use a local lake for the test. Most of the difficulties were due to apprehension on the part of the owners concerning the use of the explosive anchors and Rhodamine-B fluorescent dye in the test.

### POTOMAC RIVER FIELD TEST

The lower Potomac River southeast of Colonial Beach, Virginia, was selected as the location for the second test. This particular area of the Potomac River was selected because it afforded the correct depth, currents, and bottom conditions required to subject the barrier and deployment techniques to more severe environmental conditions than those experienced at the lake site in Sugar Grove, West Virginia. Slightly modified deployment techniques, reflecting results of the previous test, were used in this test.

Because the barrier deployment site was approximately 7 mi from the shore base, it was necessary to transport the packaged barrier to the deployment site, rather than tow it to the site as was done in the lake test. To accomplish this, a small catamaran platform about 18 ft long was designed and constructed. This platform incorporated the gantry used on the small boat in the lake test, a large box for the packaged barrier, and a set of large rollers for launching and retrieving the barrier; the platform was not powered.

The barrier system was prepared for deployment the week before the test. The barrier was dried in the sun, and the air and water bladders were filled and inspected for leaks. A number of small tears were located and easily repaired using fabric patches and cement. The barrier was then repackaged. The foam flotation used in the lake test was left out of the packaged barrier, but a 3/8-in. nylon rip cord was included. With the foam flotation omitted, the barrier was much easier to package and handle.

Preparation of the other equipment needed for deployment was accomplished according to the same general procedures used in the previous test. Extra batteries for firing the anchors and extra materials for cleaning the anchor fuze bodies were packed with the anchor system. In addition, load cells for two of the mooring legs and a current meter with a recorder output were included with the test equipment.

## PALM BEACH FIELD TEST

Because of the premature termination of the second field test (described later), a third field test was conducted near Lake Worth Inlet, Palm Beach, Florida. The reasons that this test was conducted at this location were that tidal currents of 1 to 2 knots were available and there was good underwater visibility for observation of certain stages of deployment and aspects of the in-place barrier.

During the week before the test, the barrier was again inspected, repaired, and repackaged. Several of the plastic hose-to-pipe fittings on the air bladder penetrations were found to be broken and were replaced. The foam flotation that was removed after the first field test was replaced, and the nylon rip cord was replaced with a polypropylene rip cord which would float when free of the barrier. The masking tape bindings were replaced with 1.5-in. wide fiber duct tape. This tape was put on two layers thick for most of the barrier and three layers thick at points where higher stresses might occur. By experimentation, it was found that this tape was readily torn by the rip cord.

Five fuze bodies for the explosive anchors were obtained from EDO Western Corporation. Each of these was completely assembled and readied for use. Two anchors were assembled to the extent that all that was required to render them ready for use was to load the powder charge, mount them on their firing stands, and connect the anchor pendant. Thus, two of the anchors could be deployed quickly and only a portion of the total refurbishment procedure would have to be performed to ready additional anchors for firing. The difficult and time-consuming task of refurbishing the fuze body would already be accomplished.

## EVALUATION OF PROTOTYPE SYSTEM

### Deployment

For evaluation purposes, deployment of the barrier has been divided into four steps, each of which is essentially independent of but sequential to the others.

#### Temporary Mooring--

In the beginning of the program, it was thought that the best way to accurately install the explosive anchors was to moor the barrier temporarily in place on the surface and then use the barrier as a pattern for placing the anchors. To use the barrier as a pattern for placing the anchors, it must (1) arrive at the scene of the spill with or before the explosive anchors, (2) be pulled very taut so that the anchor pattern will be accurate and the bottom of the barrier will be pulled tight (which is required for a good bottom seal) when the barrier is permanently moored, and (3) be left in place on the surface while the explosive anchors are being installed.

In the first test of the system on the still lake (West Virginia), temporary mooring of the barrier presented no problem. It was towed 600 ft to the deployment site and moored in approximately 40 min by 2 men in a 12-ft boat equipped with a 5 hp outboard motor. During the second test in open water (Potomac River), mooring the barrier proved somewhat more difficult, taking approximately 80 min. During this test, the river was flowing at approximately 1 knot, and positioning of the barrier with the small boat was more difficult. In addition, the motions of the barrier caused by waves made it impossible to pull the barrier as taut as in the first test. Because of problems associated with the explosive anchors and insufficient daylight, it was not possible to install all of the anchors during the first day, and as a result, the barrier was left in the temporary moor for the night. Winds and waves caused by bad weather broke the tape bindings on the barrier during the evening and, as a result, the barrier became unfurled. The test was discontinued, and the barrier was recovered.

For the third field test (Palm Beach, Florida), a "template" was used instead of the barrier for accurately placing the anchors. The template worked very well and was pulled taut even though there was a current of approximately 1 knot and small waves. Mooring of this template required approximately the same amount of time as was required for mooring the barrier in the first test. The explosive anchors were placed very accurately, but replacement of the template with the barrier after the anchors had been installed required about the same amount of time as was required to moor the template. Thus, the explosive anchors were placed more accurately, and the barrier was not put into the water until the explosive anchors were in place. However, an additional 40 min were consumed using this procedure.

As a result of these experiences, we believe that the best plan is to include the template as part of the deployment system, but only to be used as the situation requires. This decision will have to be made by the On-Scene Coordinator. As an example, if the explosive anchors (because of their lighter weight) can reach the spill scene hours before the barrier, then it would be advisable to install the explosive anchors using the template while waiting for the barrier to arrive.

The time required to install the barrier or template in a temporary moor is reasonable considering the small, slow boat used for the job. If a slightly larger and more powerful boat with a reverse drive (the 5 hp motor used in the field test did not have reverse drive) were used, the time probably could be shortened by 10 to 15 min because the boat could move around faster and maneuver better.

Explosive Anchors--

The installation of the explosive anchors is the single most time-consuming portion of deployment and is also that portion that offers the opportunity for the greatest reduction in time. Two segments of the anchor installation can be discussed individually.

The first segment is the actual installation of the anchors, i.e., the time from which the boat with the anchors leaves shore, the anchors are installed, and the boat returns to shore. In the field tests, all of the anchors were installed using the small boat equipped with a 5 hp outboard motor and a lightweight gantry with a hand winch. Because the motor did not have a reverse drive, it was difficult to maneuver the boat in a current. This was aggravated by the fact that it took about 5 min to lower the anchors to the bottom because the electrical leads and firing line had to be taped to the lowering line. Retrieving the gun barrel and stand (75 lb combined weight) (after firing the anchors) took longer than lowering the anchors. In addition, time was required to connect the firing line to the firing box and fire the anchors.

If the bottom-contact-fired anchors were used rather than the remote electrically fired type, approximately 10 min could be saved at each firing. It should be realized that this type anchor must be placed accurately the first time, since it fires upon initial contact with the bottom. With a reasonable amount of practice dropping a dummy anchor in waves and currents, the skill of the boat operator could be developed to assure a high probability of accurate placement of the anchors. The possibility of an occasional inaccurate placement of an anchor is thought to be a good tradeoff against the time saved by using bottom-contact-fired anchors. The heavy stands, firing box, and firing cable also would not be required.

The other segment of anchor installation that requires a large amount of time, 30 to 40 min per installation, is refurbishing or rebuilding the anchor gun after each firing. Based on the field tests, we believe that five completely ready-to-fire anchors and one spare should be used in deploying the barrier. These anchors should have the anchor pendants attached and should be packed in individual boxes for ease of handling. The main powder charge should be left out of the gun barrel, but should be packed in the same box as the anchor. All that should be required to ready an anchor for firing would be to install the powder charge and load the anchor on the boat.

If the suggestions mentioned above were implemented, we believe that the time required to install an anchor, including a short over-water transit, could be reduced from approximately one hr to 15 to 20 min. Based on the experience of the field tests, it is evident that functionally (i.e., firing and penetration), the anchors operated exceptionally well. They are very well suited for their intended application.

Pull-Down--

Both the pull-down grip and the mooring grip worked very well, although there are some modifications that could be made to the grips that would make their installation much easier and probably cut the total time for installation of the mooring devices from approximately 1 hr to about 30 min.

As presently constructed, the grips must be slipped on the end of the anchor pendant because the grips have fixed tabs on the sides to prevent the grips from coming off the cable. If these tabs were modified so that they were movable, the grips could be slipped on the anchor pendant sideways, which would save time.

Also, if the shackle on top of the mooring grip were replaced with some type of quick-connecting hook, this grip would be easier to connect to the anchor's ring on the barrier. In addition, some type of quick attachment device on the bail of the mooring grip would make attachment of the end of the pull-down line quicker. The present method requires that the line be knotted and then taped to prevent the knot from possibly becoming untied. In making both of these modifications, it should be realized that it is very important to minimize the combined height of the pull-down grip and the mooring grip, since the strength belt on the barrier (Figure 3) cannot be brought any closer to the bottom than this distance.

The force required to pull down the barrier was somewhat larger than anticipated. The addition of another winch on the deployment vessel would facilitate pull-down of the barrier. This winch would not have to be mounted on the gantry frame, but preferably would be mounted low in the boat so that the end of the pull-down line could be brought over the stern of the boat and onto the winch. If another boat with a more powerful motor is available, such as was used in the Palm Beach Field Test, this boat can be used to pull down the barrier.

Another small problem that occurred was that two of the pull-down grips did not fall all the way to the bottom of the anchor pendant when installed because of kinks in the wire anchor pendant. A diver found it an easy job to slide the grips over the kink, and this problem can be easily solved in the future by maintaining a strong tension on the pendant while sliding the pull-down grip to the bottom.

Inflation--

The time required to inflate the flotation collar fully was approximately 1 hr using a 10 SCFM compressor. This time could be reduced significantly by simply supplying air at a higher rate. One means would be to use regulated air from compressed air cylinders. The capacity of the flotation collar is approximately 600 $ft^3$, which is the equivalent to the air contained in 9 standard SCUBA diving tanks or two large "T" cylinders. The combined weight of enough of either of these cylinders to supply the air would be less than 250 lb. Using compressed air cylinders, the time required to inflate the barrier could probably be reduced to about 10 minutes. This is a tradeoff that should be considered for an operational unit.

The most serious problem concerning inflation of the barrier was that the air bladders leaked, and, as a result, the flotation collar could not be filled with air. This problem, although serious, can readily be solved with changes in the design and materials of the flotation collar or by intermittent pumping. Even if compressed air is used to inflate the flotation collar, an air compressor should still be on hand for use in the

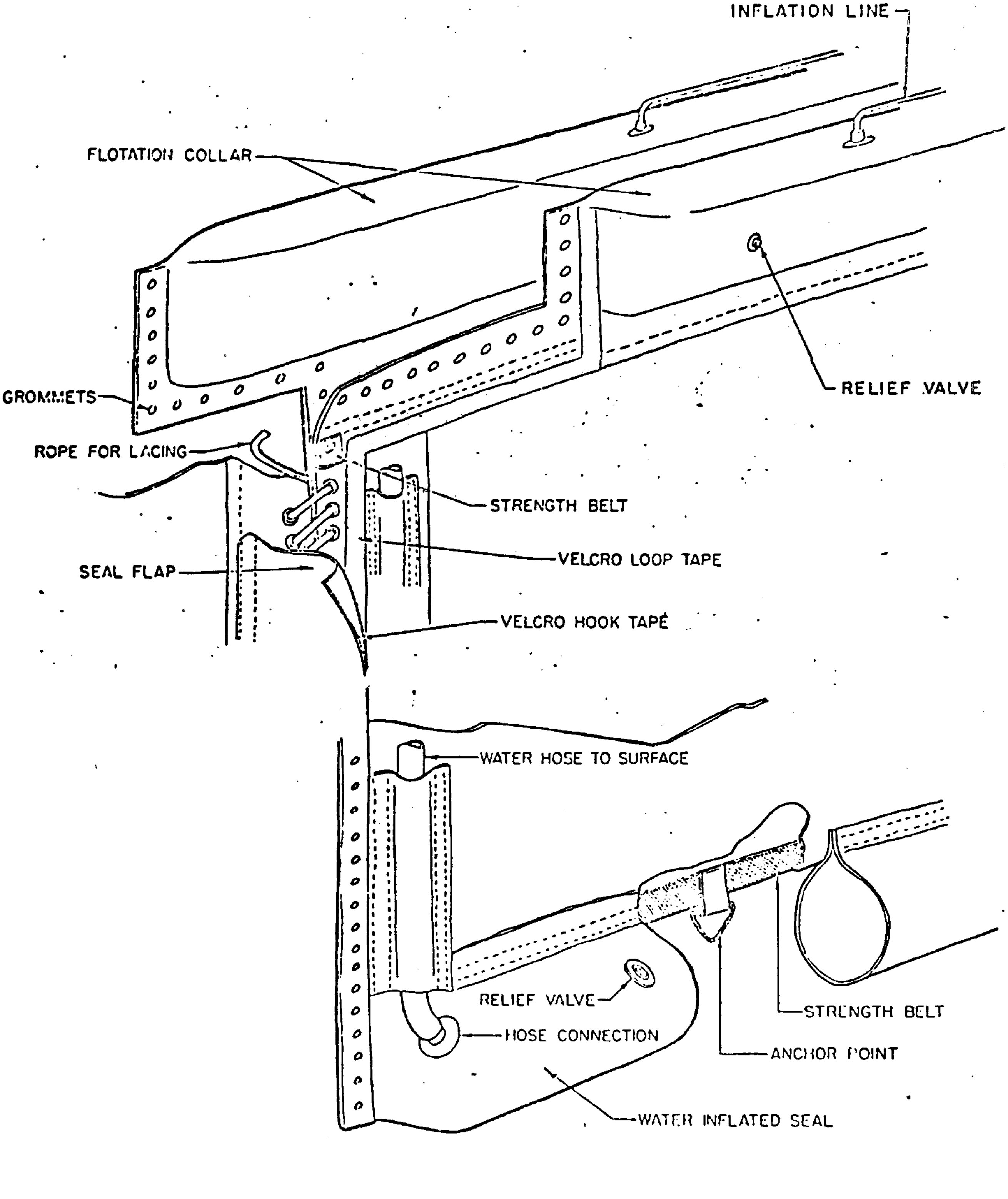


Figure 3. Details of barrier construction.

event that the collar develops a leak. The 10 SCFM compressor supplied with the system is sufficient to keep up with small leaks, but, if time permits, a larger one should be obtained once the barrier is deployed.

A less serious problem which occurred during the first test was that some of the tape bindings did not break. During the third test, this did not appear to be a problem because the barrier was pulled down tight against the bottom. When inflation began during the third test, the barrier immediately "popped" to the surface; however, because of leaks in the flotation collar, it did not continue to rise, and the rip cord that was installed after the first test was used to break the bindings. It is suspected that if the flotation had not leaked, the barrier would have "popped" up without the use of the rip cord; however, it is advisable to retain the rip cord in the packaged barrier as an added measure of safety.

The time required to fill the bladder seal on the bottom of the barrier is dependent on the rate at which liquid is pumped into it. The bladder has a capacity of approximately 10,000 gal. There are no easy solutions to shorten the time required to fill this bladder since any equipment that will pump liquid at a high enough rate to fill the bladder in a short time will also be heavy. In addition, it is not as important that the seal bladder be filled as quickly as the air bladder, unless the spilled or leaking substance has a low solubility and is more dense than water. The best solution for filling the seal bladder probably is to include the 100 gpm water pump with the system, and to try to locate a larger pump near the site of the spill. Preferably, this will be a mud pump so that the seal bladder can be filled with sand or mud to weigh it down.

## Ability of Barrier to Contain a Spill

The ability of the barrier to contain the spilled hazardous material is dependent upon the "tightness" with which the barrier encloses the spill source and the ability of the barrier to maintain its structural integrity. The barrier did not maintain its structural integrity in the third field test; however, it is believed that this problem can be corrected. Because of the structural failure of the barrier, there was no opportunity to put dye inside the barrier during the Palm Beach Field Test. However, visual inspection by a diver indicated that the barrier was pulled down tight against the bottom for its full circumference and there would be little chance for pollutants inside the barrier to leak out. This observation confirmed the results of the still water test at Sugar Grove, West Virginia, when enough Rhodomine-B fluorescent dye was put inside the barrier to form a deep red solution. For the next 22 hr, the water around the barrier was checked for dye using a fluorometer capable of detecting a few parts of dye per billion parts of water. No dye was detected, which indicates that the barrier would contain a pollutant.

Visual observation of the barrier at the time of failure in the 1972 Palm Beach test indicated that the barrier wall tore initially in the vicinity of anchor No. 1. The barrier wall continued to tear away from the strength belt for almost the full circumference of the barrier until the barrier was "feathered" in the current and the dynamic load was released.

Close inspection of the barrier after the test indicated that the initial tear probably occurred at a sewn seam where the barrier wall was attached to the strength belt. At this sewn seam, the barrier wall was comprised of two thicknesses of fabric sewn on each side of the strength belt. These two pieces of fabric were joined in an electronically welded joint above and below the strength belt. Above the welded joint located above the strength belt, the barrier wall was a single layer of fabric (Figure 3).

It is believed that dynamic pressure on the barrier wall caused the fabric to pull very hard at the sewn seam. The pressure of the stitches on the fabric caused the fabric to begin to fail in a tensile mode. As soon as a short length of the wall had failed in this mode, the fabric began to fail in a tear mode. The fabric will, of course, fail much easier in the tear mode since all of the load is put on the few fibers at the tear point. After tearing for a few yards through the double layer of material at the sewn seam, the tear jumped up the barrier wall just above the welded joint where it continued for the circumference of the barrier.

In the direction of the No. 5 anchor, the tear spread for almost the full length of the barrier, while in the direction of the No. 2 anchor it went only approximately 20 ft until it was checked by the 2-in. webbing in the vertical joint. Here it continued upward along the webbing until it reached a point just under the flotation collar. That the tear was checked by the 2-in. webbing and then ran up alongside the webbing, suggests that had vertical belts been included in the barrier, they would not have prevented failure.

Another area of the barrier design where failure occurred is that of the seams in the bladders. The barrier, as presently designed and constructed, uses a simple type of seam for the bladders. Although this seam has an adequate vertical strength, and material tests during the construction of the barrier indicated adequate strength of the joint, the electronic weld did fail by peeling and the row of stitching down the middle of the electronic weld prevented the bladder from bursting. The flotation collar was pneumatically tested after construction by pumping it up with the air compressor until the relief valves vented. All of the valves operated properly, which indicates that failure of the seam was not caused by overpressurization. Instead, it is believed that the electronic weld "peeled" in a long-term creep mode when the bladders were pressurized during the first field test.

Construction of the bladders using an improved type of joint will solve this problem and will decrease the strength of the bladder significantly. The only disadvantage of using this method is that it is more costly.

The laced joint with seal-flap performed very well during the tests. At no time did the Velcro fastener material used to fasten the seal come apart. This was true even during the second field test in the Potomac River when the barrier was retrieved from the water without undoing the vertical seam, which involved much handling of the barrier. The only disadvantage of the laced seam is that it would be rather difficult and time-consuming to put together when the ends of the barrier must be joined during deployment, as would be the case if the barrier were being deployed around a large spill source that was protruding above the water surface and there were no way to lift the barrier over the source. In this case, it would be better if the barrier were fitted with a large zipper. Such a zipper, ruggedly constructed of nylon, can have a tensile strength perpendicular to its length of over 300 lb/in.

The material that was used for construction of the barrier, Herculite "20," was obviously not of sufficient strength, at least in the areas where failure occurred. Nevertheless, after being handled and deployed three times, the material did not show a significant amount of wear and tear from these operations, except for some small tears and abraded spots on the air bladder. Although other materials should be considered if the barrier is redesigned, the Herculite material should be a prime candidate. It has a higher tear strength than most other materials of equivalent weight and is available in stronger and more abrasion-resistant grades.

The structural design, if made adequate for low current conditions, probably also will be adequate for small wave conditions, such as were observed in the third field test. The barrier was observed to be essentially transparent to the waves observed in this test (heights up to 2 ft, wave length 5 to 50 ft). As long as sufficient slack is available in the barrier skirt, the surface flotation should conform closely to the water surface and not create significant dynamic loads on the barrier.

As a final comment on the structural design of the barrier, it should be noted that the barrier is not yet an optimized design and does not represent the end-product of a significant design effort. Although it did not perform as well as desired or expected, it was useful in evaluating the operational aspects of deploying the barrier, which was the primary purpose of the program. With the proper design effort, the barrier could be made to work properly and to have the desired structural integrity.

## SECTION 6

## FIELD DEMONSTRATION OF THE MODIFIED BARRIER

Phases 1 and 2 of this project were completed in May 1972. This was followed by Phase 3 wherein a new barrier was fabricated which incorporated the recommendations of Phases 1 and 2. These modifications and improvements to the new barrier were as follows:

- The Herculite "20" fabric was replaced by a heavier type known as Herculite "LR-210."
- The flotation collar was reinforced by doubling the fabric.
- The area around the strength belt was reinforced by doubling the fabric.
- The anchoring points were reinforced more heavily.
- Quality control of the electronically welded joints was much more rigorous.

Field demonstration tests, consisting of two deployments and recoveries of the newly fabricated barrier, were then carried out between June 9 and July 6, 1976.

The test site was located in Lake Worth, a coast-parallel back-barrier lagoon located between the towns of Palm Beach and Riviera Beach, in Florida (Figure 4). The site was selected because of (1) appropriate water depth (25 ft), (2) water clarity on flood tide suitable for photographic documentation, (3) currents up to 2 knots, (4) accessibility to support facilities, (5) protection from severe storms, and (6) the opportunity to compare results with those of a previous test conducted at this site in 1972.

Changes in regulations since 1972 made it necessary to obtain permits from local, state, and federal agencies before conducting the tests. Local objections to the use of propellant anchors required that the test program be modified if this site was to be used. A decision was made to "jet" mushroom anchors into the lagoon bottom to overcome these objections. The propellant anchoring system had been tested successfully on several earlier occasions and, although an integral part of the total system, its use could be avoided for this test. Local objections to the test were then dropped and the necessary permits granted.

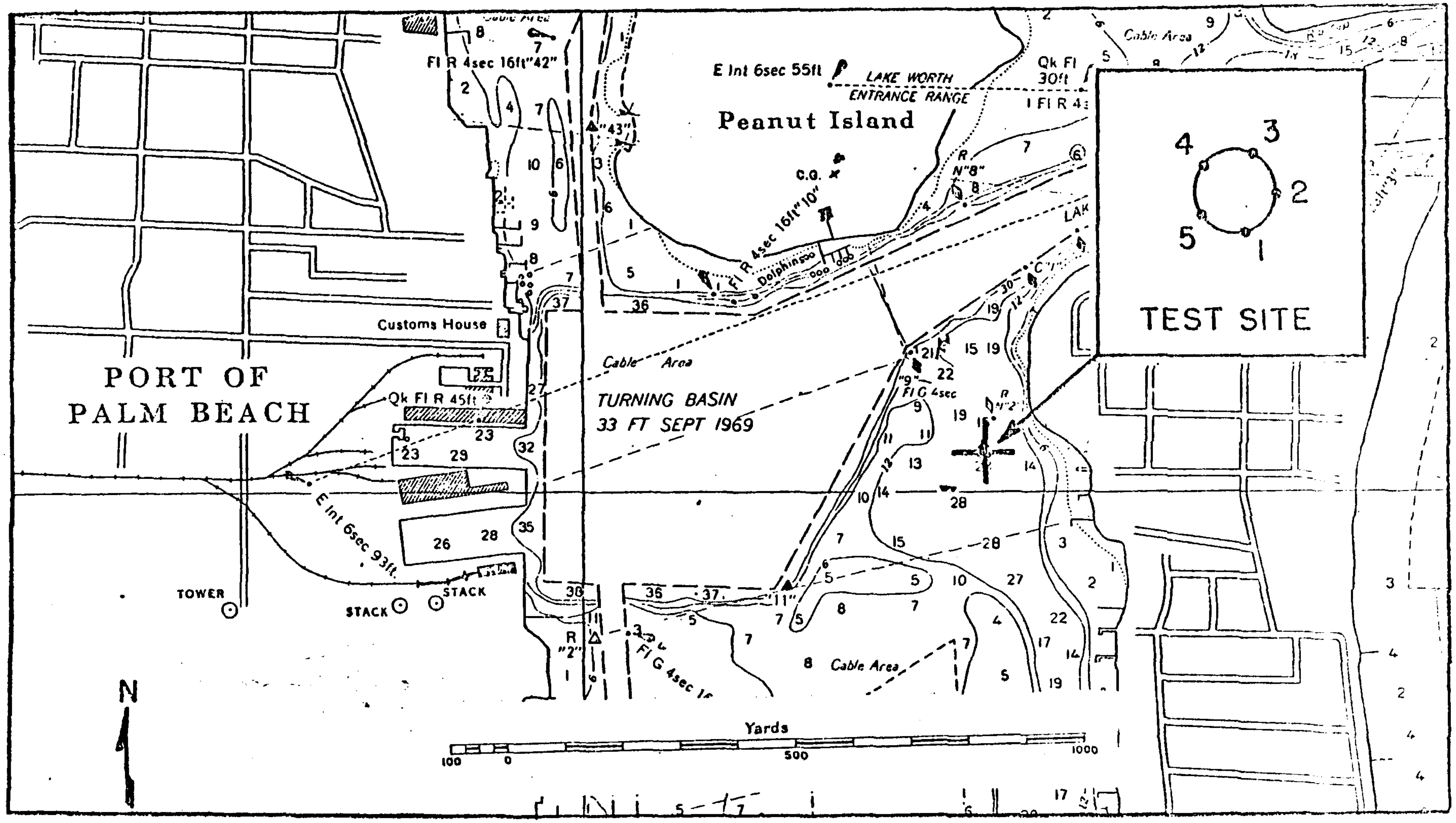


Figure 4. Palm Beach Test Site

The test program consisted of two deployments and recoveries. The first test was not completely successful because only partial deployment occurred. Nevertheless, the experience gained in handling the HMB system was extremely valuable in the second test and a marked improvement in deployment ease was noted.

The HMB arrived in Riviera Beach in early June 1976 and was unloaded from an enclosed van. It was immediately apparent that the most difficult problem associated with the HMB would be that of handling. This was to be proved in every aspect of the testing program. Loading the packaged HMB into the van had required two forklifts; unloading it with one forklift was difficult and took approximately 1.5 hr with five men.

The first site selected was changed when divers uncovered a large object where the barrier wall would have been positioned. The bottom of the alternate site was relatively flat, consisting of compact sand with a thin veneer of fine, loose sand. The only obstruction was a partially buried 55 gal drum. Two mushroom anchors were jetted in 5 ft deep at each of the five anchor points. The anchors were 30 in. in diameter. Installation of the anchors required 10 hr.

After flotation was attached to the folded barrier, it was offloaded from a van directly into the water using a crane mounted on the stern of a vessel moored at the adjacent pier (Figure 5). It was necessary to take the HMB under tow immediately to prevent it from tangling in the pilings of the pier. During the approximately 25 min while the HMB was being towed to the site, only two-thirds of the barrier was on the surface. Once at the site, additional flotation was added to the barrier to prevent it from sinking.

All mooring pendants were attached to the anchors, and the pull-down procedure begun. Some difficulty was encountered because of air trapped in folds of the HMB and an anchor which was pulled out by the upward force of the overly buoyant HMB. The anchor was replaced.

Pull-down was completed early on the next morning. When the rip cord was pulled to break the tape binding holding the barrier together, the tape refused to break and diver assistance was required. Inflation of the flotation bladders was then begun. Inspection by divers soon revealed a double twist in the barrier, preventing proper deployment and blocking the air from entering the remainder of the flotation bladder. Inflation was halted. Attempts to untwist the HMB were fruitless and immediate steps were taken to bind the barrier together as much as possible before the strong ebb tide currents began. During this operation, it was noted that several anchors had pulled out under the upward force of the twisted barrier. The currents were strong at that time, and only by extraordinary action of the handling team was loss of the HMB prevented when the last anchor was released. The partially unfolded barrier was extremely difficult to handle in the swift current and return to shore required approximately 2 hr. (Subsequent analysis suggested that improper folding was the probable reason for the twisting.) Removing the HMB from the water required seven men working 8 hr with a forklift and a crane, once again emphasizing the

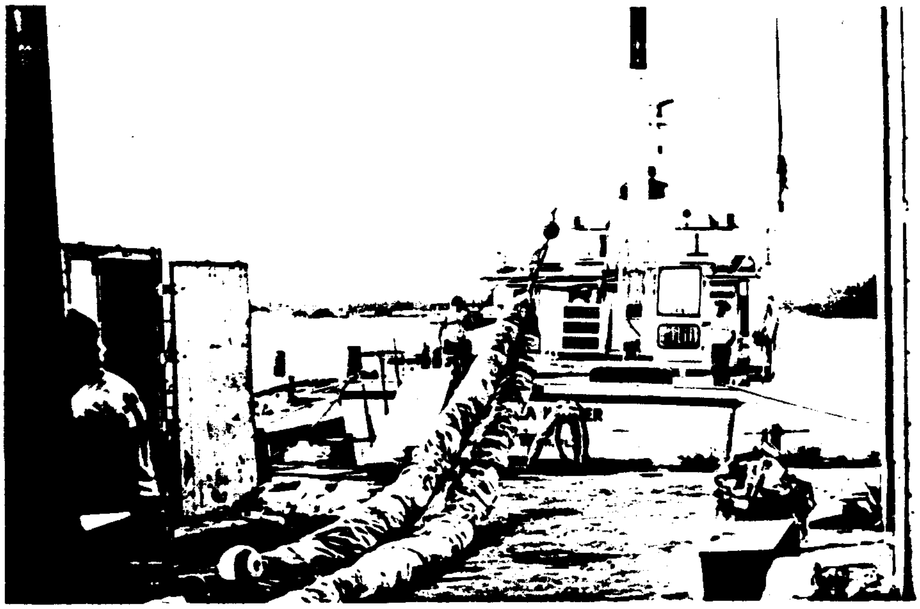

Figure 5. Unloading the HMB from the van to the water.

extreme difficulty of handling the HMB, particularly in moving it out of water.

The HMB was inspected for damage. Although there was no major structural damage, nine holes were observed in the air bladders, as well as several defective welds, numerous small holes in the water bladder, and small rips in the Herculite material near the anchor "D" rings. Repairs were made.

Discussion of the first field trial attempt produced two major changes in the deployment procedures for the second test. First, the anchoring system was changed to three equally spaced mushroom anchors at each of the five points. (It was believed that the single center point allowed the anchors to slip sideways under lateral forces and work themselves up out of the bottom.) The second change involved the towing procedure. For the second test, the folded barrier bundle would be towed by one "D" ring, with the other opposing "D" rings secured together to prevent twisting during the tow.

After the decision was made to proceed with the second test using these modifications, the HMB was refolded. This was by far the most physically demanding task in the entire operation. Many problems were encountered in the folding process, mainly because of inexperience. Seven men were used in the folding, but the compact accordian folds necessary for proper deployment and to avoid trapped air, twisting, etc. were not achieved on the first attempt. After the folding was repeated successfully, the bundle was taped together and flotation added. The ends of the bundle were brought together and laced, as shown in Figure 6. The new mushroom anchors were positioned at the test site.

On June 28, 1976 all boats were readied and the HMB was placed in the water at 0830 hr. This took 30 min using an overhead crane to unload the HMB. By 0900 hr the HMB was under tow to the site where it arrived at 0930 hr (Figure 7). The lines holding the HMB together to prevent twisting during the tow were taken off (Figure 8) and the first "D" ring attached to the mooring pendant. Pull-down began at the northern-most point and continued without major difficulty to completion at 1500 hr, a total of approximately 5 hr. Figure 9 shows the pull-down grip being attached to the mooring pendant. Figure 10 shows an underwater view of the pulldown process beginning. In Figure 11, the HMB is being pulled down with the winch system. Figure 12 shows the HMB partially pulled down and Figure 13 shows the HMB after subsequent pull-down. The thin white line near the bottom is the template used to position the anchors. When pull-down was completed, the system was ready to be inflated.

Even though the rip cord had been changed to 0.5 in. manila line, attempts to pull the rip cord from the surface failed again as the line only rolled the tape. It was again necessary for a diver to break all but two of the tape bindings. Inflation of the air bladders began, but one of the air lines kinked and a diver had to free the line. Figure 14 shows the last portion of the bladder being inflated. Several small leaks were located in the air bladder and the relief valves leaked as well, possibly

Figure 6.

Lacing air bladders together.

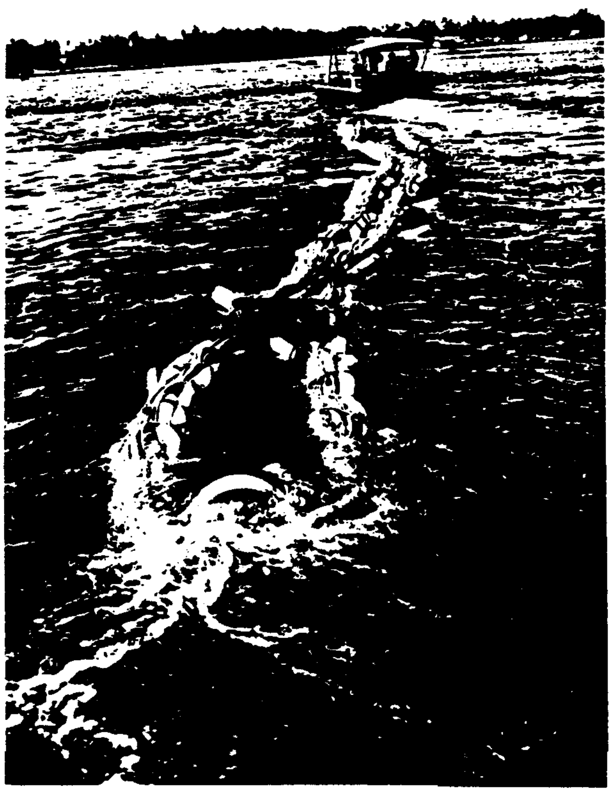

Figure 7.

HMB being towed to test site. Note the air inflation umbilical on top.

Figure 8.

Diver releasing lines holding "D" rings together for towing.

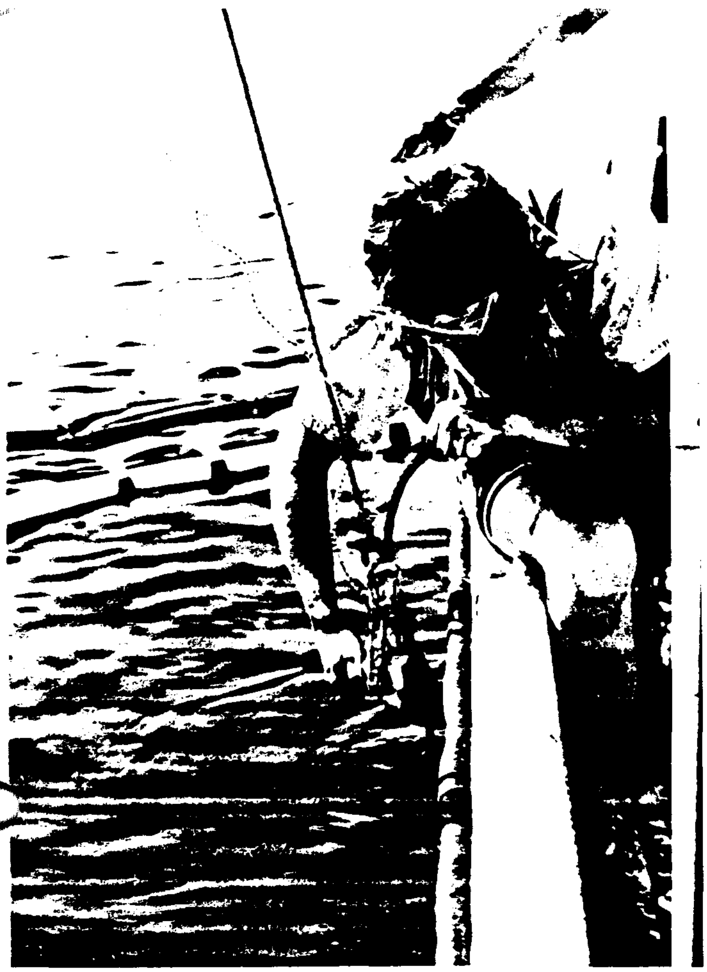

Figure 9.

Pull-down grip being attached to the mooring pendant.

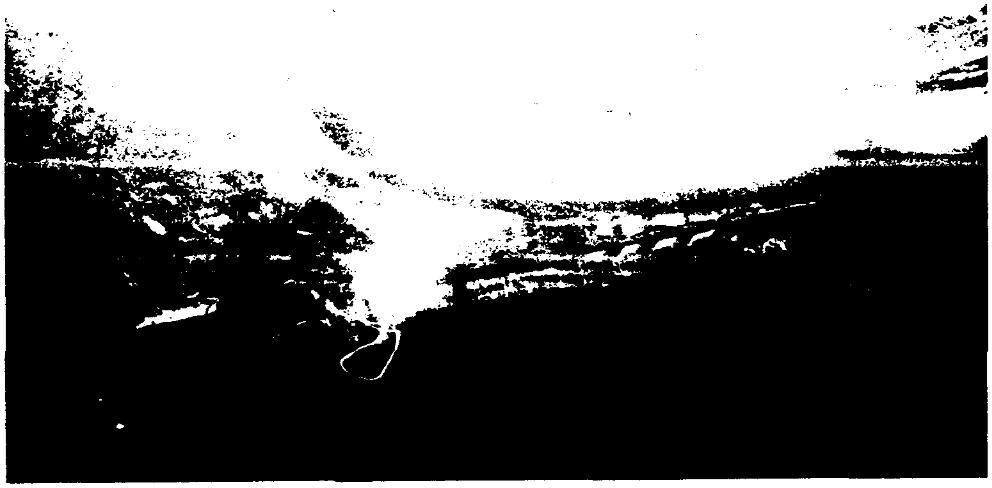

Figure 10. Underwater view of pull-down commencing.

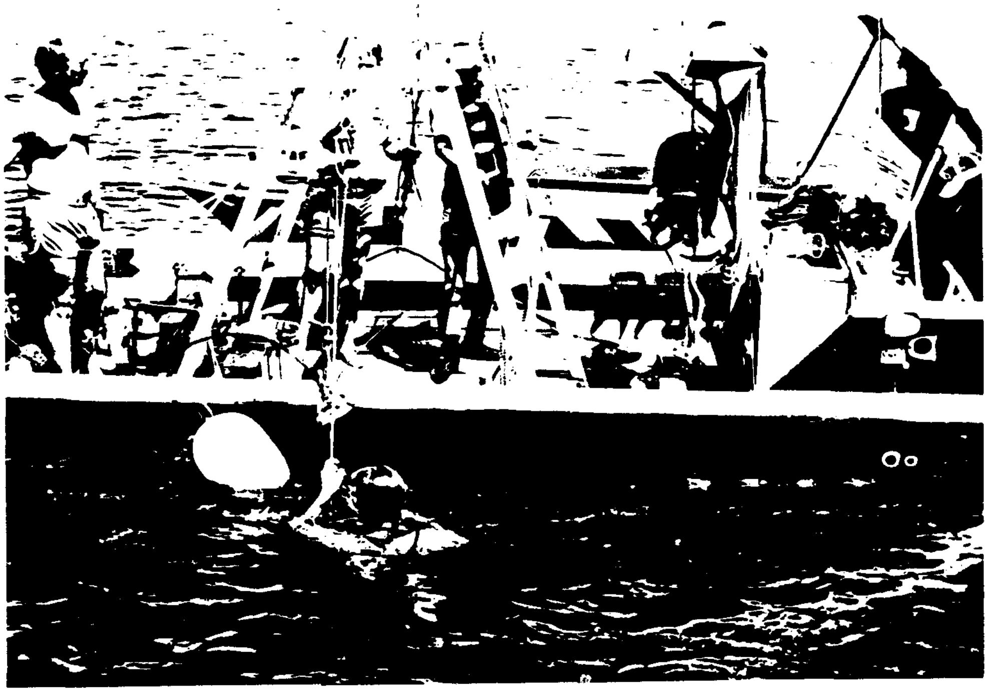

Figure 11. Winching down the HMB.

Figure 12. HMB partially pulled down.

Figure 13. Full pull-down at two adjacent anchors. Note the upward strain caused by the flotation. Also note the template (thin white line) near the bottom used in placing the anchors.

Figure 14. Nearly inflated HMB on surface.

Figure 15. Fully inflated bottom seal rising above lake floor.

due to their 0.5 psi over-pressure setting. The worst air leak was at the end of the orange air bladder inside a welded flap and was impossible to patch without destroying the weld. The air compressor ran for approximately 10 min out of every hour to counter air losses through the leaks. The barrier was on the surface by 1600 hr (Figure 15) at which time the water pump was connected, and water was pumped into the bottom seal bladder. Filling of the water bladder was also slowed because of repeated kinking of the fire hose used.

On the following day, inspection of the HMB revealed the water bladder to be four-fifths full, but not sealed against the bottom (Figure 16). Two anchors were also discovered to have pulled out of the bottom during the night. These were the old, center-attached anchors. None of the new, three-point anchors had pulled loose, and the barrier was in no danger of breaking away. The anchors that pulled out were on the south side of the barrier, which received the strongest force from the ebb tide. The dynamometer readings showed a maximum of 2000 lb of force had been reached during the night. The ebb tide currents began increasing early in the afternoon. By 1400 hr the barrier had begun changing shape, and it was completely collapsed by 1500 hr (Figure 17). Current velocities during this period are reported in the Appendix. The HMB could not be forced open and field operations were suspended for the day. In spite of this problem, it was decided to weigh down the bottom seal bladder with lead bars and attempt a dye experiment to determine any leakage points.

On the morning of June 30, 1976, the barrier was found collapsed again, although it had been observed to have opened up during the slack current the previous evening. However, within a short time, the barrier once again regained its circular shape without assistance. Divers placed 1000 lb of lead bars in the space between the HMB wall and the water bladder to seal the barrier against the bottom. Rhodamine-B fluorescent dye was placed inside the HMB at 1305 hr and current meter and fluorometer readings were taken continuously in and around the HMB during the ebb tide. As the current increased, the barrier again began changing configuration. By 1505 hr, the south side of the barrier facing the ebb current was pushed completely underwater and all the dye was lost. Measurable amounts of dye also were detected within 4 ft of the bottom, downstream of the barrier, indicating that the bottom seal was incomplete, and water was being lost under the seal. Subsequent investigation by divers revealed that the anchors on the southeast section had pulled out, leaving the bottom seal of the barrier about 5 ft above the bottom of the lagoon, thus allowing sufficient water inside to maintain pressure against the lee wall. The field test of the HMB was discontinued at that time.

The recovery process began the following day by removing the lead bars and disconnecting all but one anchor point. Several slashes were made in the bottom seal bladder to allow the water to exit while the barrier was under tow. When the final anchor was cut loose, it was impossible to tow the barrier, even against the weak flood tide current. The HMB wall was acting like an enormous sea anchor and had to be slashed to allow water to escape through the rear. An attempt also was made to cinch up the wall to the flotation bladder, but the mass of the curtain was too great to be moved

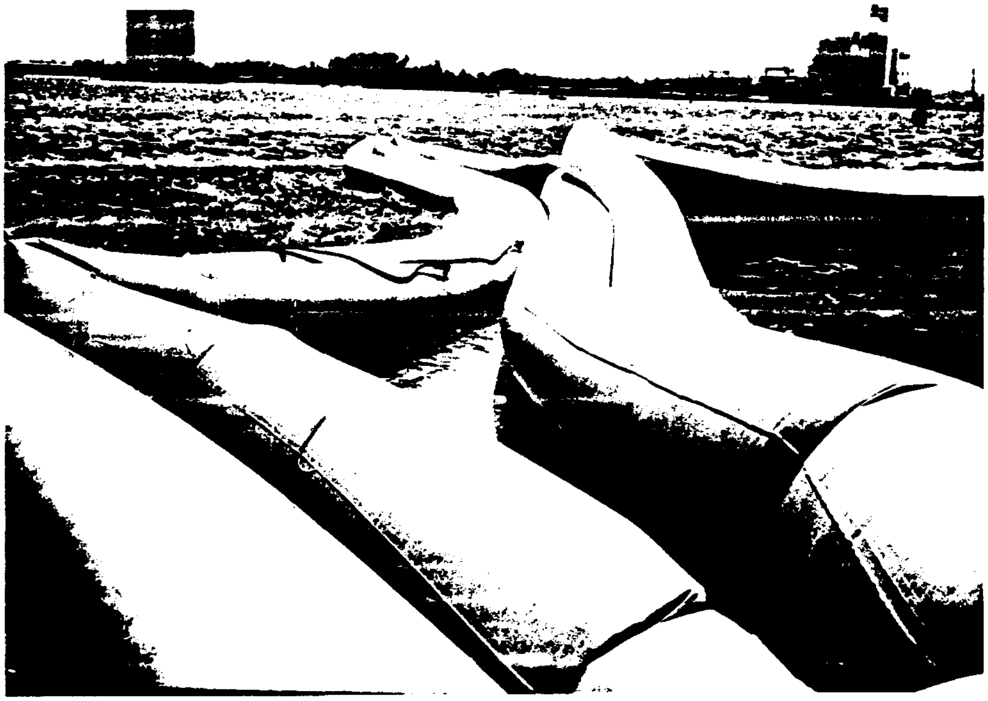

Figure 16. Fully collapsed HMB. Current was from left to right.

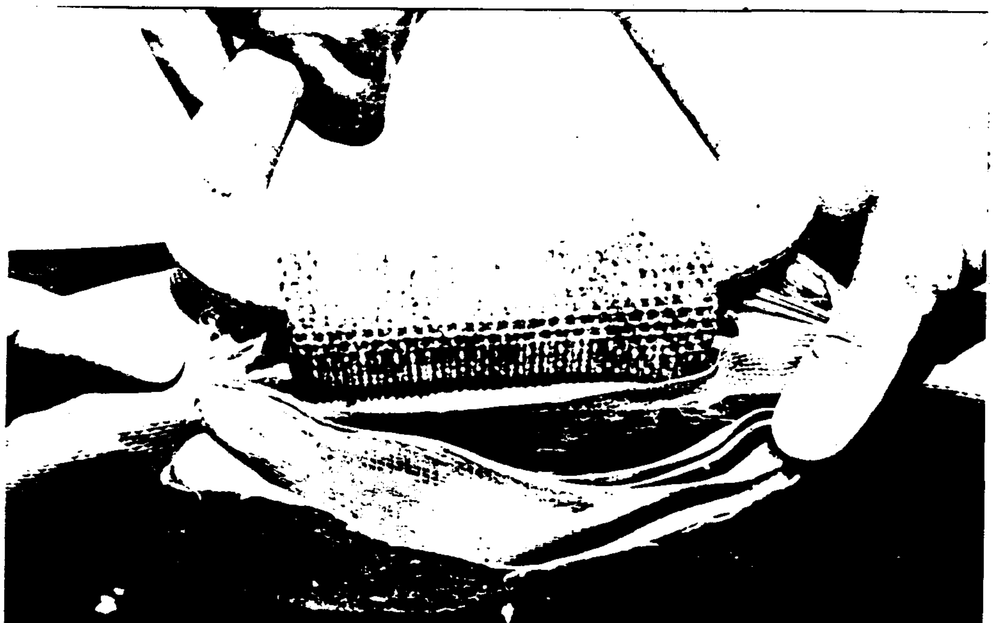

Figure 17. Tears around "D" ring.

manually. It took 2.5 hr to move the barrier to the shore base. Another 2 hr of effort by 5 men and an overhead crane was required to lift the HMB from the water onto a flatbed truck.

Inspection later revealed some structural damage, peeling welds, and several holes to the air and bottom seal bladders and the curtain wall, in addition to the intentional slashes. The barrier was folded and stored on a pallet pending further action.

## SYSTEM EVALUATION

### Temporary Mooring

The template marking the deployment positions for the anchors was staked out on the bottom instead of in its normal, floating position because of the alternate anchoring system being installed by the divers. Used in this manner, the template was very effective in guiding the divers.

### Anchoring

The preferred propellant anchoring system was not used in this test because of permit restrictions, as previously explained. The mushroom anchoring system actually used was an expedient measure and was not evaluated as part of the test. Earlier tests had shown that the propellant anchoring system was workable and was probably superior to the anchors being used in the field tests, as was confirmed by the failure of several anchors during the two tests.

### Pull-down

Both the pull-down and the mooring grips worked well. The weakest part of the pull-down system was the winch. The winch used in the test was a simple two-gear boat trailer winch that did not have the strength nor the durability for this application. It was impossible to pull the mooring pendants taut under even a slight current using this system. This prevented several pull-down grips from falling all the way to the bottom, and diver assistance was required.

In the initial test, air trapped in the HMB, combined with strong lateral forces imposed by the strong tidal currents, made pull-down extremely difficult and even caused anchors to pull out. During the second test, extra flotation had been added, and this contributed to the difficulty even though little air was trapped in the folded barrier. The flotation could not be removed prior to pull-down because the tape binding the HMB also held the flotation. An alternate method of binding and attaching flotation should be found.

Pull-down for the first test, with all its problems, took 8 hr and required 6 men. The second test pull-down, after corrective measures had been taken, still required 5.5 hr using 5 men.

## Inflation

The biggest problem encountered during inflation occurred during the first test when a twist in the barrier prevented complete inflation and cancelled the remainder of the test. Careful attention to repacking the HMB solved this problem. Another problem during both tests was breaking the tape bindings holding the HMB bundle together. In both deployment tests, using either a smooth, braided nylon rope or a rough, manila rope, respectively, as a rip cord, diver assistance still was required to cut the tape and release the HMB.

Both bottled air and a compressor were evaluated as a source of the air to inflate the upper bladder. For example, a bank of five "K" bottles, each holding 220 $ft^3$ of compressed air, is sufficient to inflate the bladder. The air compressor has the advantage that it can also be used to maintain pressure in case of leaks. Thus, in the second trial, the air compressor was operated for approximately 10 min every hour to keep the air bladder full, even with several small leaks.

As with the air hose, diver inspection found the water hose to the bottom seal bladder kinked near the intake opening. Water pressure from the pump was not adequate to hold the kink open until a larger pump was substituted. However, the bottom seal failed to function as designed when filled with water. Obviously, a higher density fluid must be pumped into the bladder to provide an effective seal against the bottom. This fluid could be a sand slurry, drilling mud, or some other dense medium. Obtaining such a material in a spill situation could present a logistical problem. In addition, some air is inevitably trapped in the bladder and causes it to arch up between the anchor points. Valves should be installed to bleed off this trapped air.

## Recovery

The HMB represents a substantial economic investment and, to be cost effective, it must be recovered - with minimal damage - to be used again.

The initial step in recovery is to drain the bottom seal bladder. This was done in the trials by cutting vertical slits in the bladder so that the dynamic pressure during towing caused the bladder to collapse and force the trapped water out through the slits. Special valves should be incorporated into an operational barrier design to allow the bladder to be purged with air or completely opened for the liquid inside to escape.

After the bottom seal is drained, the anchors on the downstream side of the barrier are released by a diver unshackling the barrier "D" rings from the pull-down grips. The final anchor is released only when the tow boat is in position and ready. This operation can be expedited by replacing the final shackle with a strong rope just before removal and then having the diver cut the rope.

It had been suggested earlier that the lacing holding the ends of the HMB together could be cut and the HMB recovered more easily by towing a single strand. This was found to be impractical because the 200 ft length would have been uncontrollable in the currents and it could not have been maneuvered around channel markers, anchored vessels and pilings. In general, towing of the HMB should be avoided if possible. A crane also must be available to lift the HMB from the water at the shore base, since it is too heavy to be recovered manually.

STRUCTURAL DESIGN

The structural design improvements incorporated into the HMB since the 1972 tests were highly successful. No major failures occurred in the Herculite LR-210 film except during recovery. Several of the electronic welds did fail by "peeling", but none of these was at a critical point.

INSPECTION, REFURBISHING, AND REPACKAGING OF SYSTEM

One year later, on July 1, 1977, the barrier was laid out at the large Perry Oceanographic Warehouse at Riviera Beach, Florida and inspected for damage. Aside from the deliberate slashes in the barrier wall and the bottom seal bladder made to facilitate recovery and towing, and several smaller tears around the "D" rings (Figure 18), the barrier was in good condition. The auxiliary equipment was also inspected and found to be in fair condition.

The large slashes in the barrier were sewed, and then two layers of the Herculite plastic film were placed over the area with Herculite CVV adhesive. The small tears were repaired in a similar manner. All compartments were then inflated with an air compressor to check for leaks (Figure 19); the minor leaks found in this manner were also repaired.

The barrier was then swept clean in preparation for repackaging. Starting with a 10-in. fold, the barrier was folded by a team of 6 to 8 people (Figures 20 and 21). When completely folded, it was tied with line every 4 or 5 ft (Figure 22) and then placed on a pallet with the aid of a forklift truck. On October 10, 1977, the barrier and the entire support system were shipped to the USEPA's Edison, NJ facility to be available for further tests.

Figure 18. Air test of HMB after repairs.

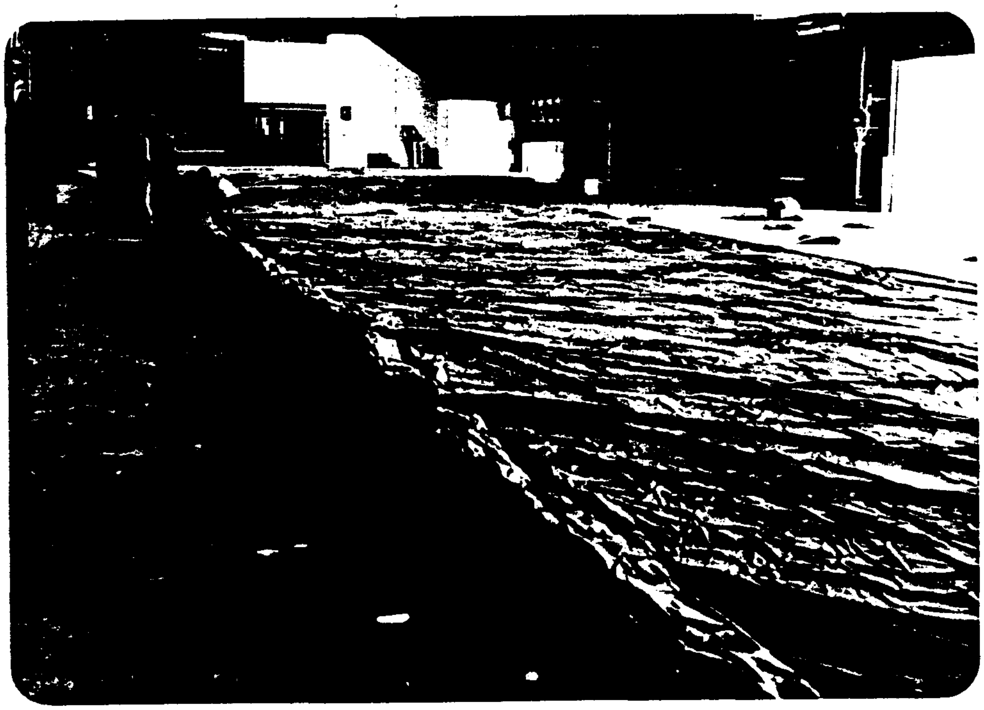

Figure 19. Start of folding HMB.

Figure 20. Folding of HMB almost completed.

Figure 21. HMB folded and tied every 4 to 5 ft.

## APPENDIX

## CURRENT VELOCITY MEASUREMENTS

This appendix summarizes the procedures used and the results obtained from current monitoring tests during the 1976 trials, while the hazardous materials barrier was being deployed and studied for its performance in the field.

Measurements of current velocity were made on June 30 and July 1 and 2, 1976, during both flood and ebb tides, to determine the effects of the tidal currents on the configuration and integrity of the HMB. Continuous current monitoring was conducted with an in-situ recording current meter; vertical profile data were collected at predetermined stations during various portions of the tidal cycle.

Current velocities were measured at a single depth using an in-situ film recording current meter installed sequentially at two stations (Stations #1 and #2) adjacent to the HMB. (See Figure 23 for station locations.) Recordings were taken at Station #1 from 1100 hr on June 30 through 1030 hr on July 1. The meter was then moved to Station #2 where recording began at 1100 hr on July 1 and continued through 0900 hr on July 2. In both cases, the meter was installed 12 ft off the lagoon bottom. Water depth at Station #1 was 24 ft and at Station #2, 18 ft.

Station #1 was selected so that currents unaffected by the presence of the HMB could be measured during both flood and ebb tide. It was located approximately 40 ft from the east side of the barrier. Station #2, located about 50 ft south of the barrier, was selected to measure the strength of the ebb current. At this location, it also provided accurate measurements of the actual current affecting the barrier, which was directly upstream during the ebb tide cycle. It was suspected that the maximum ebb currents would be stronger than the maximum flood currents. It was known that the duration of the ebb cycle was much longer than the flood cycle. This was confirmed by the data. The data from the in-situ current meter appear in Tables A-1 and A-2 for Stations #1 and #2, respectively.

In addition to collecting in-situ current data at a single depth, current velocity profiles were also made at Stations #1 and #2 to determine the relationship between speeds at a single depth and those throughout the water column. The vertical profiling data were obtained using a surface readout meter with a Bendix B10 ducted impeller sensor. Measurements were taken at depths of 15, 10, 5, and 2 ft.

The vertical profiles at Station #1 were only obtained during three closely spaced time intervals on June 30. These data, tabulated in Table A-3, confirm that current velocities at the surface are considerably higher than those at the bottom of the lagoon. The vertical profile data at Station #2 were taken on July 1, 1976. These data are reported in tabular form in Table A-4.

The current conditions encountered at the test site should be considered typical for major rivers and estuarine areas where a hazardous material might be spilled. The vertical profiles show current speeds considerably higher at the surface than at the bottom. At the surface, current velocities were frequently recorded in excess of 1.5 knots; bottom velocities were below 0.2 knot on most occasions. The HMB appears to hold its configuration well in current speeds below 0.4 knot. When speeds exceed 0.4 knot, the forces on the barrier increase and there is a tendency for the barrier to collapse, particularly at the surface. Collapse is, of course, less likely on the bottom due to both the anchoring and the substantially lower current velocities.

In areas of limited tidal height variations, the barrier can be very effective at current speeds below 0.4 knot. When deployed in locales with high tidal range, the HMB's effectiveness decreases as an inverse function of the increase in tide range. With each tide cycle, flushing of a certain percentage of the contained volume of water within the HMB was observed. Under the conditions of this test, it was virtually impossible to separate the effects of tidal flushing from those attributable to loss in general integrity of the barrier.

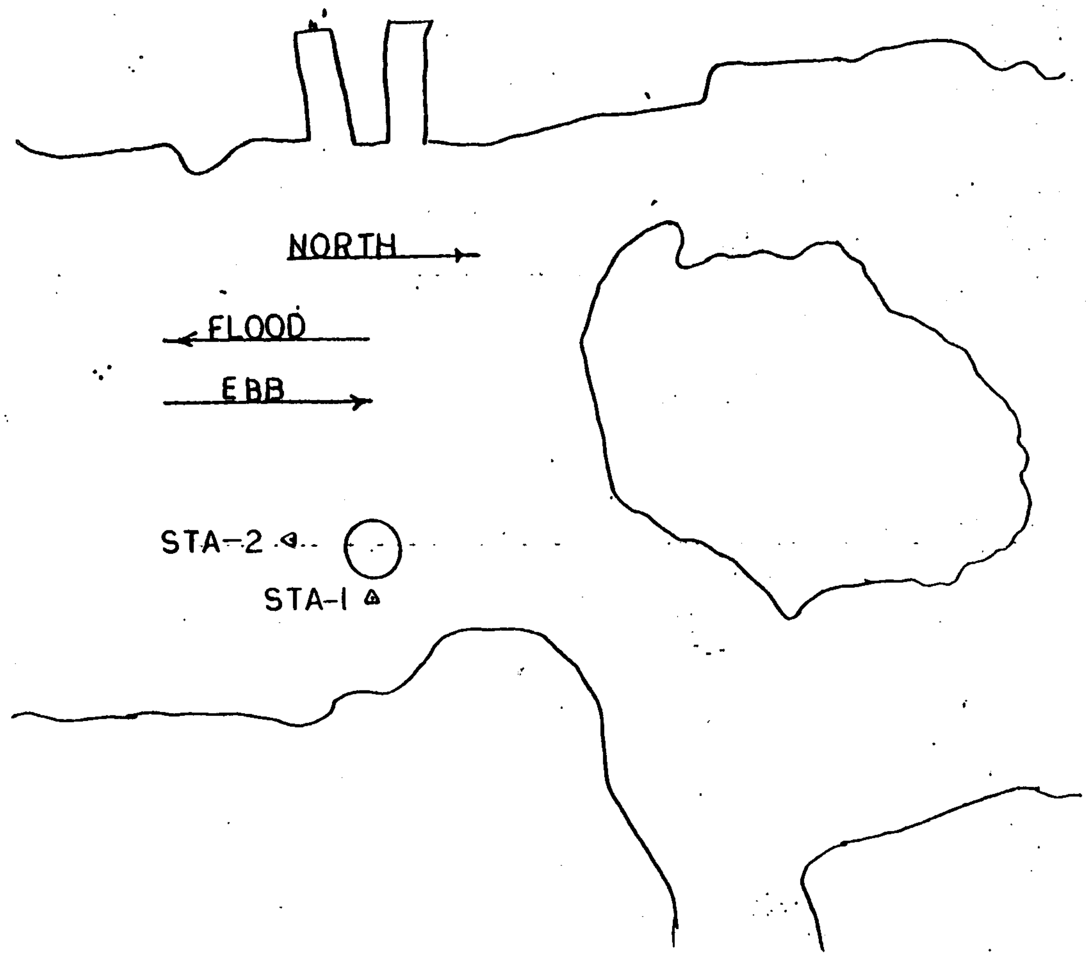


Figure 23. Current measurement stations.

TABLE A-1. IN-SITU CURRENT DATA FOR STATION 1

| Time | Speed (knots) | Time | Speed (knots) | Time | Speed (knots) |
|---|---|---|---|---|---|
| | | June 30, 1976 | | | |
| 1100 | 0.17 | 1530 | 0.22 | 2000 | 0.21 |
| 1115 | 0.10 | 1545 | 0.28 | 2015 | 0.24 |
| 1130 | 0.08 | 1600 | 0.23 | 2030 | 0.28 |
| 1145 | 0.04 | 1615 | 0.19 | 2045 | 0.24 |
| 1200 | 0.07 | 1630 | 0.20 | 2100 | 0.20 |
| 1215 | 0.05 | 1645 | 0.19 | 2115 | 0.19 |
| 1230 | 0.02 | 1700 | 0.17 | 2130 | 0.18 |
| 1245 | 0.08 | 1715 | 0.19 | 2145 | 0.15 |
| 1300 | 0.14 | 1730 | 0.16 | 2200 | 0.16 |
| 1315 | 0.13 | 1745 | 0.10 | 2215 | 0.13 |
| 1330 | 0.18 | 1800 | 0.01 | 2230 | 0.13 |
| 1345 | 0.20 | 1815 | 0.00 | 2245 | 0.09 |
| 1400 | 0.28 | 1830 | 0.00 | 2300 | 0.08 |
| 1415 | 0.14 | 1845 | 0.03 | 2315 | 0.05 |
| 1430 | 0.24 | 1900 | 0.00 | 2330 | 0.11 |
| 1445 | 0.27 | 1915 | 0.01 | 2345 | 0.12 |
| 1500 | 0.26 | 1930 | 0.22 | 2400 | 0.08 |
| 1515 | 0.24 | 1945 | 0.24 | | |
| | | July 1, 1976 | | | |
| 0015 | 0.05 | 0345 | 0.22 | 0715 | 0.02 |
| 0030 | 0.05 | 0400 | 0.25 | 0730 | 0.04 |
| 0045 | 0.00 | 0415 | 0.21 | 0745 | 0.05 |
| 0100 | 0.07 | 0430 | 0.21 | 0800 | 0.03 |
| 0115 | 0.12 | 0445 | 0.25 | 0815 | 0.12 |
| 0130 | 0.07 | 0500 | 0.23 | 0830 | 0.24 |
| 0145 | 0.13 | 0515 | 0.25 | 0845 | 0.19 |
| 0200 | 0.16 | 0530 | 0.22 | 0900 | 0.17 |
| 0215 | 0.08 | 0545 | 0.20 | 0915 | 0.22 |
| 0230 | 0.14 | 0600 | 0.21 | 0930 | 0.17 |
| 0245 | 0.20 | 0615 | 0.17 | 0945 | 0.18 |
| 0300 | 0.19 | 0630 | 0.10 | 1000 | 0.13 |
| 0315 | 0.25 | 0645 | 0.05 | 1015 | 0.11 |
| 0330 | 0.22 | 0700 | 0.01 | 1030 | 0.09 |

TABLE A-2. IN-SITU CURRENT DATA FOR STATION 2

| Time | Speed (knots) | Time | Speed (knots) | Time | Speed (knots) |
|---|---|---|---|---|---|
| | | July 1, 1976 | | | |
| 1100 | 0.08 | 1530 | 0.19 | 2000 | 0.00 |
| 1115 | 0.09 | 1545 | 0.14 | 2015 | 0.01 |
| 1130 | 0.10 | 1600 | 0.15 | 2030 | 0.00 |
| 1145 | 0.10 | 1615 | 0.18 | 2045 | 0.04 |
| 1200 | 0.09 | 1630 | 0.22 | 2100 | 0.04 |
| 1215 | 0.10 | 1645 | 0.24 | 2115 | 0.04 |
| 1230 | 0.10 | 1700 | 0.14 | 2130 | 0.05 |
| 1245 | 0.06 | 1715 | 0.16 | 2145 | 0.05 |
| 1300 | 0.05 | 1730 | 0.15 | 2200 | 0.18 |
| 1315 | 0.03 | 1745 | 0.11 | 2215 | 0.05 |
| 1330 | 0.05 | 1800 | 0.09 | 2230 | 0.12 |
| 1345 | 0.10 | 1815 | 0.12 | 2245 | 0.01 |
| 1400 | 0.13 | 1830 | 0.05 | 2300 | 0.01 |
| 1415 | 0.13 | 1845 | 0.04 | 2315 | 0.01 |
| 1430 | 0.13 | 1900 | 0.01 | 2330 | 0.01 |
| 1445 | 0.15 | 1915 | 0.05 | 2345 | 0.01 |
| 1500 | 0.11 | 1930 | 0.05 | 2400 | 0.08 |
| 1515 | 0.14 | 1945 | 0.04 | | |
| | | July 2, 1976 | | | |
| 0015 | 0.07 | 0315 | 0.20 | 0615 | 0.05 |
| 0030 | 0.04 | 0330 | 0.20 | 0630 | 0.09 |
| 0045 | 0.07 | 0345 | 0.25 | 0645 | 0.05 |
| 0100 | 0.10 | 0400 | 0.25 | 0700 | 0.05 |
| 0115 | 0.05 | 0415 | 0.23 | 0715 | 0.02 |
| 0130 | 0.05 | 0430 | 0.20 | 0730 | 0.02 |
| 0145 | 0.09 | 0445 | 0.19 | 0745 | 0.04 |
| 0200 | 0.10 | 0500 | 0.25 | 0800 | 0.01 |
| 0215 | 0.12 | 0515 | 0.18 | 0815 | 0.05 |
| 0230 | 0.12 | 0530 | 0.18 | 0830 | 0.01 |
| 0245 | 0.14 | 0545 | 0.17 | 0845 | 0.01 |
| 0300 | 0.21 | 0600 | 0.14 | 0900 | 0.02 |

TABLE A-3. VERTICAL CURRENT PROFILES
FOR STATION #1

June 30, 1976

| Time (hr) | Depth (ft) | Current (knots) |
|---|---|---|
| 1400 | -2 | 1.30 |
| | -5 | 0.50 - 0.80 |
| | -10 | 0.46 - 0.48 |
| | -13 | 0.18 - 0.30 |
| | -15 | 0.22 - 0.28 |
| | Bottom | 0.20 |
| 1410 | -2 | 1.30 |
| | -5 | 0.75 |
| | -8 | 0.65 - 0.80 |
| | -10 | 0.50 - 0.70 |
| | -15 | 0.30 - 0.55 |
| | -20 | 0.30 - 0.50 |
| | -22 | 0.60 - 0.70 |
| 1420 | -2 | 1.25 |
| | -5 | 1.00 |
| | -10 | 0.50 |
| | -15 | 0.20 |
| | -20 | 0.10 |

TABLE A-4. VERTICAL CURRENT PROFILES - STATION 2

July 1, 1976

| Time (hr) | Depth (ft) | Current (knots) | Time (hr) | Depth (ft) | Current (knots) |
|---|---|---|---|---|---|
| 1245 | -2 | 0.2 | 1345 | -1 | 0.65 |
| | -5 | 0.1 | | -2 | 0.5 |
| | -10 | 0.1 | | -5 | 0.5 |
| | -15 | 0.05 | | -10 | 0.4 |
| | | | | -15 | 0.3 |
| 1315 | -2 | 0.15 | | -17 | 0.25 |
| | -5 | 0.0 | | | |
| | -10 | 0.0 | 1350 | -1 | 0.8 |
| | -15 | 0.0 | | -2 | 0.68 |
| | -17 | 0.15 | | -5 | 0.56 |
| | | | | -10 | 0.32 |
| 1324 | -2 | 0.4 | | -15 | 0.22 |
| | -5 | 0.1 | | -17 | 0.18 |
| | -10 | 0.0 | | | |
| | -15 | 0.0 | 1355 | -1 | 0.88 |
| | -17 | 0.0 | | -2 | 0.75 |
| | | | | -5 | 0.52 |
| 1326 | -2 | 0.4 | | -10 | 0.36 |
| | -5 | 0.05 | | -15 | 0.12 |
| | -10 | 0.05 | | -17 | 0.2 |
| | -15 | 0.1 | | | |
| | | | 1400 | -1 | 0.92 |
| 1331 | -2 | 0.45 | | -2 | 0.86 |
| | -5 | 0.3 | | -5 | 0.62 |
| | -10 | 0.1 | | -10 | 0.1 |
| | -15 | 0.1 | | -15 | 0.1 |
| | -17 | 0.025 | | -17 | 0.1 |
| 1338 | -1 | 0.6 | 1405 | -1 | 0.9 |
| | -2 | 0.5 | | -2 | 0.84 |
| | -5 | 0.45 | | -5 | 0.64 |
| | -10 | 0.2 | | -10 | 0.22 |
| | -15 | 0.1 | | -15 | 0.0 |
| | -17 | 0.1 | | -17 | 0.0 |
| 1340 | -1 | 0.75 | 1420 | -1 | 0.95 |
| | -2 | 0.6 | | -2 | 0.84 |
| | -5 | 0.35 | | -5 | 0.75 |
| | -10 | 0.2 | | -10 | 0.0 |
| | -15 | 0.15 | | -15 | 0.02 |
| | -17 | 0.1 | | -17 | 0.02 |

Table A-4
(continued)

| Time (hr) | Depth (ft) | Current (knots) | Time (hr) | Depth (ft) | Current (knots) |
|---|---|---|---|---|---|
| 1430 | -2 | 0.75 | 1515 | -2 | 1.3 |
| | -5 | 0.6 | | -5 | 0.5 |
| | -10 | 0.4 | | -10 | 0.30 |
| | -15 | 0.18 | | -15 | 0.0 |
| | -17 | 0.10 | | -17 | 0.0 |
| 1440* | -1 | 0.02 | 1520 | -2 | 1.4 |
| | -2 | 0.02 | | -5 | 0.5 |
| | -5 | 0.04 | | -10 | 0.1 |
| | -10 | 0.05 | | -15 | 0.12 |
| | -15 | 0.07 | | -17 | 0.08 |
| | -17 | 0.0 | | | |
| | | | 1525 | -2 | 1.5 |
| 1450 | -2 | 1.3 | | -5 | 0.8 |
| | -5 | 0.52 | | -10 | 0.2 |
| | -10 | 0.2 | | -15 | 0.24 |
| | -15 | 0.0 | | -17 | 0.1 |
| | -17 | 0.0 | | | |
| | | | 1530 | -2 | 1.5 |
| 1455 | -2 | 1.05 | | -5 | 0.52 |
| | -5 | 0.7 | | -10 | 0.42 |
| | -10 | 0.16 | | -15 | 0.3 |
| | -15 | 0.0 | | -17 | 0.1 |
| | -17 | 0.0 | | | |
| | | | 1540 | -2 | 1.5 |
| 1500 | -2 | 1.1 | | -5 | 0.9 |
| | -5 | 0.6 | | -10 | 0.2 |
| | -10 | 0.0 | | -15 | 0.1 |
| | -15 | 0.0 | | -17 | 0.2 |
| | -17 | 0.0 | | | |
| | | | 1545 | -2 | 1.15 |
| 1505 | -2 | 1.3 | | -5 | 0.6 |
| | -5 | 0.64 | | -10 | 0.0 |
| | -10 | 0.0 | | -15 | 0.2 |
| | -15 | 0.2 | | -17 | 0.1 |
| | -17 | 0.0 | | | |
| | | | 1555 | -2 | 1.3 |
| 1510 | -2 | 1.0 | | -5 | 0.36 |
| | -5 | 0.6 | | -10 | 0.1 |
| | -10 | 0.0 | | -15 | 0.05 |
| | -17 | 0.0 | | | |

Table A-4
(continued)

| Time (hr) | Depth (ft) | Current (knots) | Time (hr) | Depth (ft) | Current (knots) |
|---|---|---|---|---|---|
| 1605 | -2 | 1.2 | 1635 | -2 | 1.55 |
| | -5 | 0.6 | | -5 | 0.8 |
| | -10 | 0.1 | | -10 | 0.26 |
| | -15 | 0.1 | | -16 | 0.08 |
| | -16 | 0.1 | | | |
| | | | 1645 | -2 | 1.6 |
| 1615 | -2 | 1.3 | | -5 | 0.67 |
| | -5 | 0.45 | | -10 | 0.2 |
| | -10 | 0.1 | | -16 | 0.17 |
| | -16 | 0.0 | | | |
| | | | 1655 | -2 | 1.6 |
| 1625 | -2 | 1.6 | | -5 | 0.5 |
| | -5 | 0.76 | | -10 | 0.0 |
| | -10 | 0.28 | | -16 | 0.2 |
| | -16 | 0.0 | | | |
| | | | 1705 | -2 | 1.5 |
| 1630 | -2 | 1.6 | | -5 | 0.56 |
| | -5 | 1.0 | | -10 | 0.21 |
| | -10 | 0.36 | | -16 | 0.18 |
| | -16 | 0.05 | | | |

* Wind came up; 15 to 20 knots.