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Toussaint River Unexploded Ordnance (UXO) Demonstration Dredging Project

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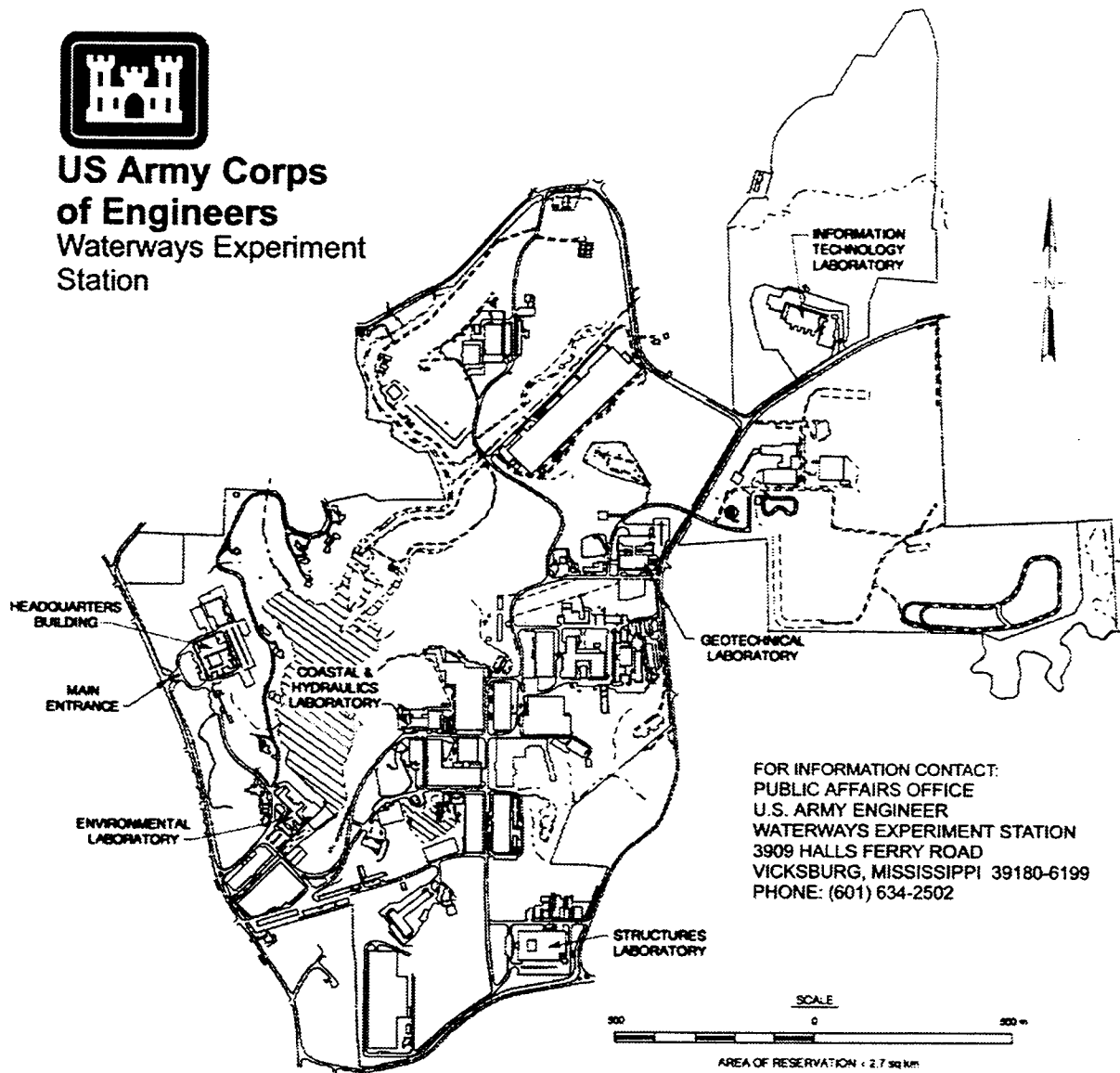
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Preface

The demonstration described herein, and data resulting from it, were the result of research conducted under the Defense Environmental Restoration Program - Formerly Used Defense Sites (DERP-FUDS) of the U.S. Army Corps of Engineers, unless otherwise noted. Partial funding for the WES contribution was provided by the Dredging Operations Technical Support (DOTS) Program.

The report was prepared by Messrs. Timothy L. Welp and James E. Clausner, Coastal and Hydraulics Laboratory (CHL), and Mr. Raymond L. Pilon, U.S. Army Engineer District, Buffalo. Mr. Welp was under the administrative supervision of Mr. William L. Preslan, Chief, Prototype Measurement and Analysis Branch, Coastal Sediments and Engineering Division (CSED), CHL. Mr. Clausner was under the administrative supervision of Ms. Joan Pope, Chief, Coastal Evaluation and Design Branch, CSED. Mr. Thomas Richardson was the Chief, CSED. Dr. James R. Houston was Director, CHL; Mr. Charles C. Calhoun, Jr., was Assistant Director, CHL.

Dr. Robert W. Whalin was Director of WES at the time of publication of this report. COL Robin R. Cababa, EN, was Commander.

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1 Introduction

In 1991, the U.S. Army Engineer District, Buffalo, initiated a Civil Works dredging operation at the mouth of the Toussaint River approximately 60 km (37 miles) east of Toledo, Ohio (Figure 1). The new works project consisted of establishing a 46-m- (150-ft-) wide Federal navigation channel from the mouth of the Toussaint River out into Lake Erie, a reach of approximately 640 m (2,100 ft). The authorized channel depth was 1.2 m (3.8 ft) below low water datum. The contract involved a cutterhead dredge and was nearly complete (38,000 m³ out of 42,000 m³ (50,000 yd³ out of 55,000 yd³)) when ordnance, a 106-mm artillery projectile, was found jammed in the cutterhead. The Buffalo District immediately halted dredging operations following this incident.

The presence of the 106-mm round, which later turned out to be inert, can be explained by the fact that the Toussaint River is adjacent to the former Erie Army Depot, a previous Department of Defense facility used for testing and proof firing of Army ordnance. In the context of this document, ordnance will be defined as bombs, warheads, missiles, artillery, mortar ammunition, etc.; any device that is explosive or otherwise designed to cause damage to personnel and material. Unexploded ordnance (UXO) will be defined as items of explosive ordnance that have failed to function as designed or have been abandoned, discarded, or improperly disposed of, yet still remain capable of functioning. Inert ordnance are ordnance items that have either functioned as designed, leaving inert carriers; were manufactured inert to serve specific training purposes; or are fragments remaining from detonated ordnance.

Camp Perry was established in 1907 by the state of Ohio for the training of the state National Guard. Part of the camp was used to establish the Erie Army Depot in the spring of 1918. For almost a half century (1918-1965), this site was used by the Department of the Army for testing and proof-firing of artillery and as an ordnance storage and issue center (U.S. Army Engineer District, Rock Island 1993). Several impact areas in Lake Erie were established by the Erie Army Depot to test fire artillery barrels. The Erie Army Depot was succeeded by the General Services Administration in 1966 and closed in 1967. The heavy-caliber lake impact areas, which are currently used by the Army National Guard at Camp Perry, are significantly smaller in size than those documented as being active by Erie Army Depot in the earlier years. Ordnance pattern impact areas included surfaces classified as lake (39,000 hectares (96,000 acres) of Lake Erie), wet land

(133 hectares (329.5 acres) including the beach), and dry land (Figure 1). Under the Defense Environmental Restoration Program (DERP), this prior U.S. Army installation and impact area, or Formerly Used Defense Site (FUDS), is subject to Federal site cleanup action (Pope, Lewis, and Welp 1996).

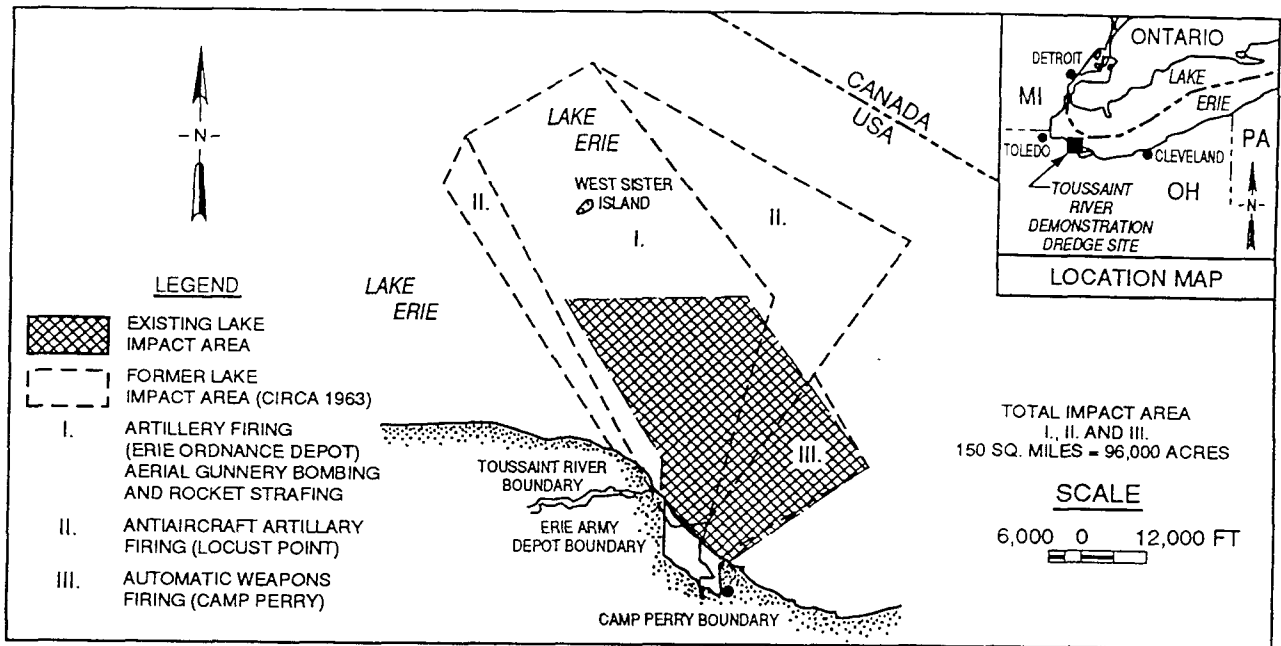


Figure 1. Location of the Toussaint Dredging Demonstration and Erie Army Depot and Camp Perry lake impact zones

Between 1 September and 9 December 1992, Explosive Ordnance Disposal Technologies, under contract to the U.S. Army Engineer Division, Huntsville, removed or exploded in place all visible ordnance as well as ordnance within 0.3 m (1 ft) of the Lake Erie beach surface from the still-water surface to 152 m (500 ft) inland. A total of 5,438 ordnance items, from small-caliber cartridges to large pieces such as 165-mm projectiles, were identified and removed. The largest populations of ordnance were 20 mm (24 percent), 60 mm (23 percent), 106 mm (15 percent), and 105 mm (14 percent). Approximately 20 percent of the ordnance was classified as UXO (Pope, Lewis, and Welp 1996).

During September 1993, the U.S. Army Engineer Waterways Experiment Station (with site assistance from the Huntsville Division, the Buffalo District, and several contractors) conducted a multi-instrumented geophysical and oceanographic field investigation to document site geological conditions and the influences of various coastal processes on ordnance distribution patterns. In particular, the concentrations of suspected ordnance lakeward of the FUDS beach, on the beach, and in the entrance channel of the Toussaint River were documented relative to geomorphic features, sediment type, and the geography of Erie Army Depot. Ordnance concentrations and site geology were investigated by a variety of methods; land and underwater magnetometers, ground-penetrating radar (GPR),

side-scan sonar, electro-magnetics, a remotely operated vehicle, site narratives, and historical information. The results from this study indicate onshore and limited alongshore ordnance migration patterns (Pope, Lewis, and Welp 1996).

The Buffalo District, under the auspices of DERP-FUDS, conducted a demonstration dredging project in the Toussaint River (10 July through 26 October 1995) that was specifically designed to address the ordnance threat. The purpose of this demonstration project was to evaluate the operational effectiveness of a clamshell bucket dredging process, modified with additional safety precautions and engineering controls, for dredging ordnance-contaminated channel sediment. An important design consideration was to safely recover potentially dangerous ordnance for proper disposal, as opposed to UXO exclusion-type designs that depend on keeping ordnance “on the bottom.”

2 Dredging System Description

The dredging methodology selected for the demonstration consisted of removing river bottom material with a modified clamshell bucket dredge and depositing it on separation screens placed over the hoppers of bottom-dump scows. These screens were designed to pass sediment and retain UXO by a combination of gravity flow and water jet fluidization. As dredged material was dumped onto the screen surface, it was visually monitored by an Explosives Ordnance Disposal (EOD) contractor (under contract with the Huntsville Division) through a remote-controlled camera system to detect UXO as the sediment “sifted” through. When a suspicious object was detected, dredging ceased and the item was positively identified. If determined to be an ordnance hazard, it was recovered, transported to shore, and disposed of by the EOD contractor. After the bottom-dump scow was filled, the sediment/debris remaining on the screen was cleared by the EOD contractor, and the dredged material was deposited in a nearshore disposal site.

Shoreline Contractors of Lakewood, Ohio, was awarded the dredging contract, which was based on the maximum number of demonstration dredging hours that could be provided within the allocated \$500,000 cost constraint. The hourly cost rate included all costs associated with anticipated weather delays, equipment repair, passage of public boaters, transport and disposal of dredged material, and all other items necessary to meet the contract specifications. A 24-m (80-ft) boomed Bucyrus Erie 61-B tracked crane with a 2.3-m³ (3-yd³) toothed-clamshell bucket was used for excavating, with an additional 2.3-m³ (3-yd³) bucket held in reserve in case the first bucket was damaged by UXO detonation. This crane was driven onto the spud barge “Shoreline 785” and temporarily secured. The *Shoreline 785*, a 24-m by 12-m by 2-m (78.5-ft by 40-ft by 7-ft) steel-hulled barge with a hydraulically driven spud system, was specifically designed and built (launched 2 June 1995) for the project.

Engineering controls to counter health hazards due to potential UXO detonation consisted of enclosing the crane operator's booth with a 6.4-mm- (0.25-in.-) thick steel plate protection barrier with a viewport consisting of 64-mm- (2.5-in.-) thick polycarbonate laminate. This viewport provided the equivalent resistance of

6.4-mm- (0.25-in.-) thick mild steel plate (Figure 2). The 24-m (80-ft) crane was required because it allowed a minimum separation distance of 16 m (52 ft) between the operator and the clamshell bucket (also a protective barrier). The Huntsville Division designed the appropriate safeguards, including the protective barrier and the separation distance, using the computer program CONWEP to analyze effects of a potential detonation (i.e., equivalent weight of TNT, peak overpressure, fragmentation, etc.). This analysis was based on a 106-mm anti-tank round, the maximum-sized UXO perceived as a threat.



Figure 2. Crane operator's protective barrier

The clamshell excavated medium-sized sand (average d_{50} of 1.2 mm) from the navigation channel and dumped onto the scow secured “alongside” as shown in Figure 3. The project used two 65-m³ (85-yd³) capacity bottom-dump scows 14 m by 6 m by 2 m (45 ft by 20 ft by 6 ft) to transport dredged material to the disposal site. These scows were pushed with the work boat *Falcon*, an 11-m by 4-m by 0.8-m (36-ft by 12-ft by 2-1/2-ft) motor vessel equipped with pusher knees and propelled by a 350-hp diesel engine. The shallow drafts of the *Shoreline 785*, *Falcon*, and both scows allowed dredging to be conducted in water depths as shallow as 1.2 m (4 ft).

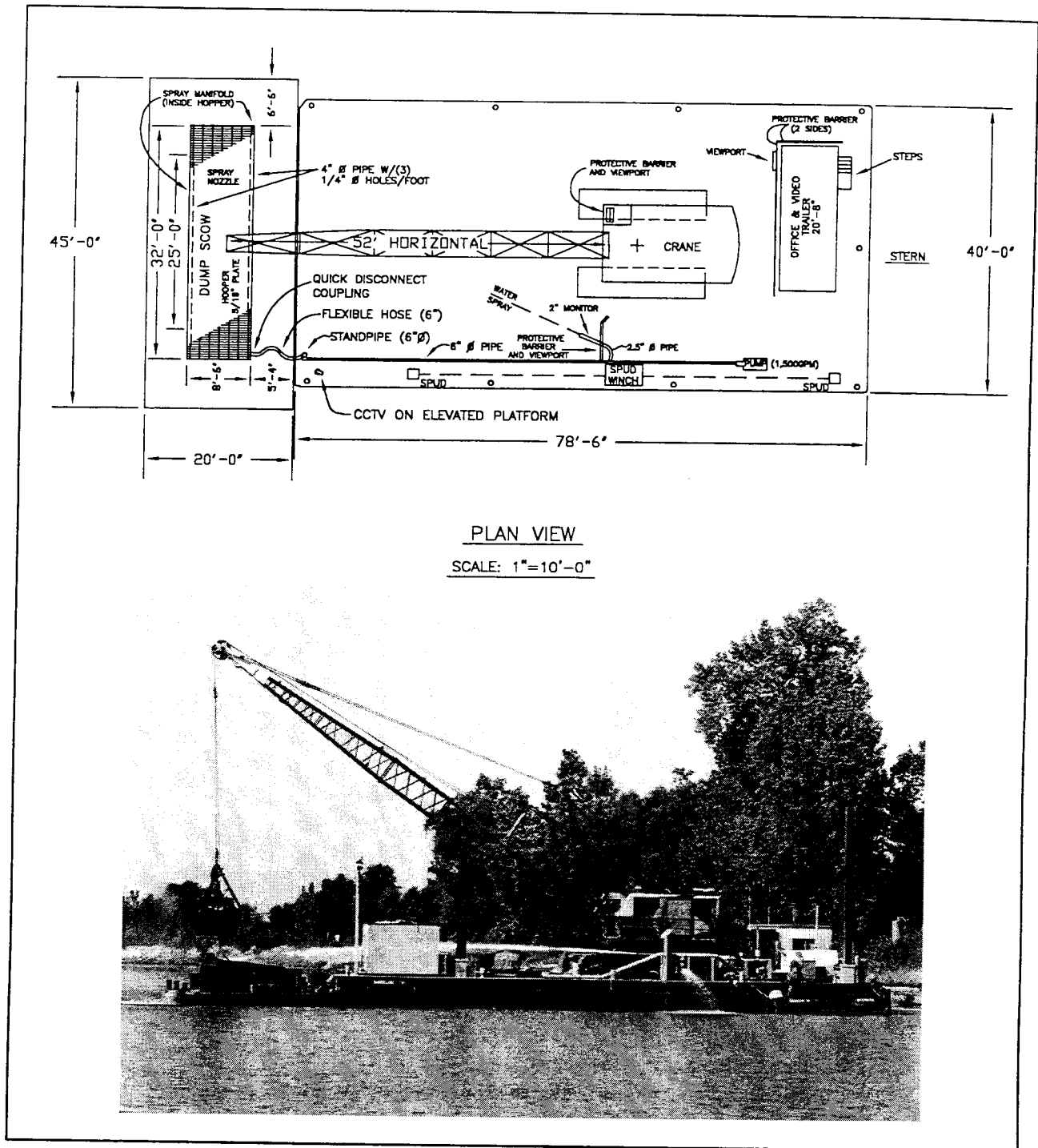


Figure 3. Deck layout (Courtesy of Shoreline Contractors, Inc.) and photograph of UXO dredging system

The separation screen was mounted over each scow on an I-beam support structure welded to the deck and inclined approximately 10 deg from the horizontal plane (Figure 4). In the event of a detonation, the screens were

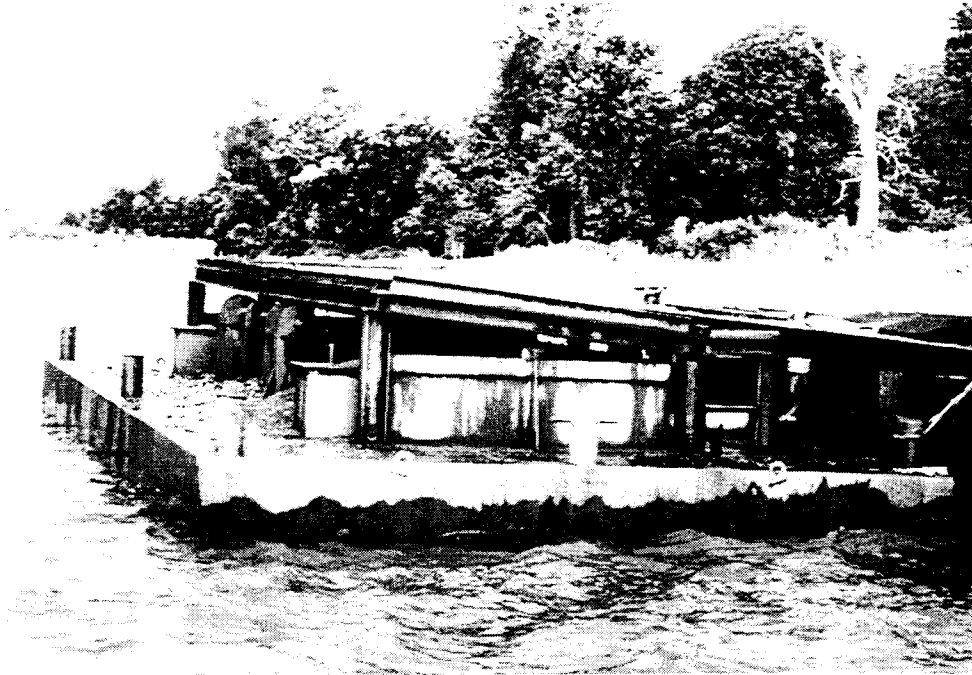


Figure 4. Scow and separation screen

designed and constructed to allow damaged sections to be replaced or repaired. Each screen's 25-m² (272- ft²) total surface area was divided into two equal sections, 5 m by 2.6 m (16 ft by 8-1/2 ft) each that were removable to facilitate repair of detonation-induced damage and also to clean debris by lifting one side with the crane. The contract specifications required that the maximum screen opening dimensions be 19 mm (0.75 in.) in one direction and 127 mm (5 in.) in the other direction. These dimensions were based upon the design objective of retaining 20-mm projectiles. The screens used by the contractor initially consisted of coal-tar epoxy-coated bar grating with 19-mm by 114-mm (0.75-in. by 4.5-in.) openings that were 19 mm (0.75 in.) deep, but these dimensions were later modified as the project progressed (these changes are discussed later in the paper). Contract specifications required that the screen be constructed such that the maximum allowable opening dimensions were not to be exceeded even when it (the screen) was fully loaded with a design load of 4.6 m³ (6 yd³) of dredged material (approximately 8 tonnes (9 short tons)).

As the clamshell operator dumped dredged material onto the screen, a jet of water was manually directed into the dredged material from the water cannon station. This water jet facilitated screen throughput by fluidizing sediment and disintegrating the more cohesive clumps. The spraying system used a 100-mm (4-in.) (discharge) fire pump rated for 95 L/sec (1,500 gpm) at 24 bars (350 psi). This pump's discharge was coupled to a 152-mm (6-in.) expansion pipe system with a three-valve flow control system that regulated flow to the water cannon, excess overboard discharge, and the scow's internal spray system (Figure 5). The

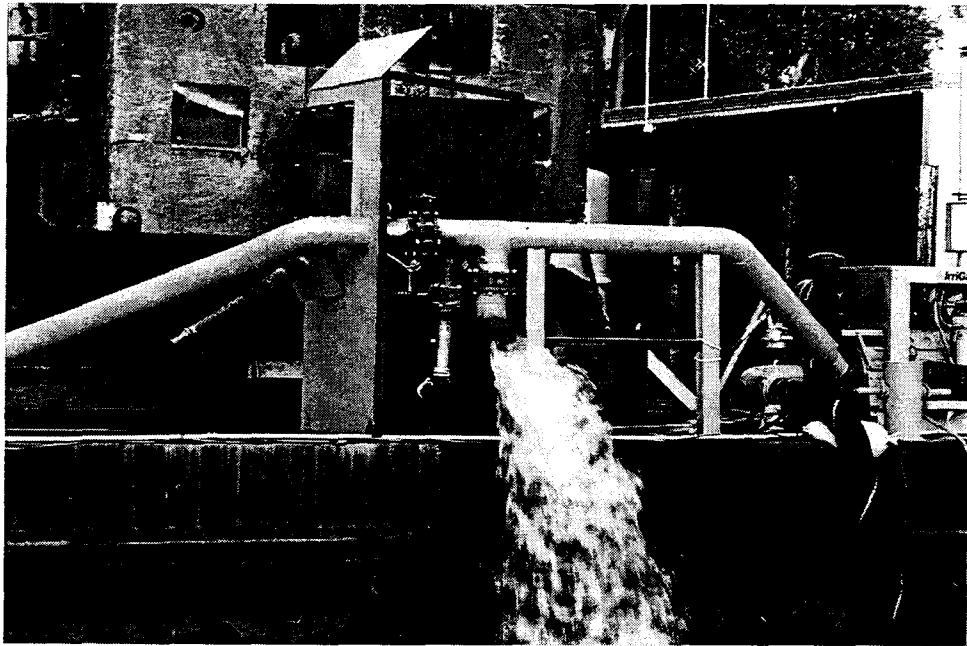


Figure 5. Fluidization valve-control system

water cannon control valve regulated flow through a 64-mm (2.5-in.) flexible hose that was connected to a fire-fighting nozzle with a 64-mm- to 25-mm- (2.5-in. - to 1-in.-) diam reducer configuration (Figure 5). The water cannon operator was protected from potential UXO detonation by a protective barrier with the same construction materials and thicknesses as the crane operator's enclosure previously described. The nozzle was set in a gimbaled mount located immediately below the viewing port and provided with a 6.4-mm- (0.25 in.-) thick steel rectangular protective barrier to cover the gimbal opening (Figure 6). This mount, comprised of two concentric swivels, provided the water cannon operator with two degrees of freedom to direct the water jet to any location on the entire screen surface.

A scow's internal spray system consisted of a perforated-pipe manifold that was mounted on the interior port and starboard sides of the hopper immediately below the separation screen. A 152-mm (6-in.) water supply pipe ran from the water cannon station and terminated with a section of flexible hose equipped with a quick-disconnect coupling (Figure 3). The flexible hose would be connected to the scow's internal manifold pipe when the scow was brought alongside. The internal manifold consisted of a 100-mm (4-in.) pipe with 6.4-mm- (0.25-in.-) diam holes (10 holes per meter (3 holes per ft)) oriented such that when water was pumped to the circuit, water jets were applied in a regularly spaced pattern to the underside of the screen. This system was designed to improve throughput by applying additional fluidization forces to the underside of dredged material placed upon the screen.

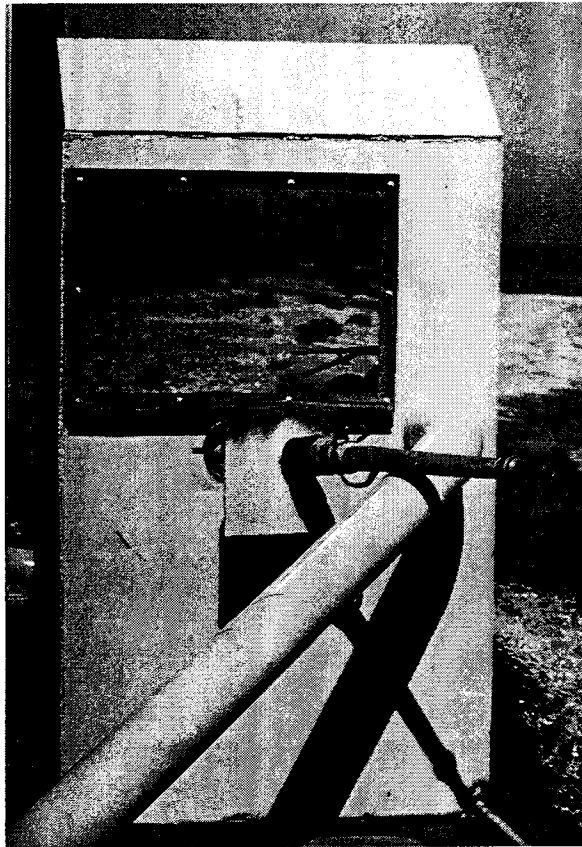


Figure 6. Water cannon operator's station

an explosion-proof and waterproof enclosure equipped with remote-controlled pan and tilt capabilities (Figure 7).

An operator in the OBST controlled the camera's zoom, pan, and tilt functions. A color video monitor and time-lapse recorder were connected to the camera via a fiber-optic link to provide color-corrected professional-quality images (Figure 8). The CCTV field of view provided coverage of the entire screen surface. As a surveillance system backup, one EOD person monitored the screening process by looking out the view port with binoculars.

The screening process was visually monitored by EOD personnel in the observation trailer (OBST). Human Factors Applications Incorporated (HFA) of Holicong, Pennsylvania, provided EOD support during the demonstration in the form of equipment and personnel to locate, identify, recover, transport, and dispose of ordnance encountered. The OBST was equipped with a steel protective barrier and polycarbonate viewport on the side facing the screen (Figure 3). During the actual dredging, all personnel except the water cannon and crane operators were stationed inside the OBST. A closed-circuit television (CCTV) high-resolution camera lens was mounted on a 4.6-m (15-ft) mast near the screening area. The camera's 10X f1.8 motorized zoom lens with auto iris was housed in

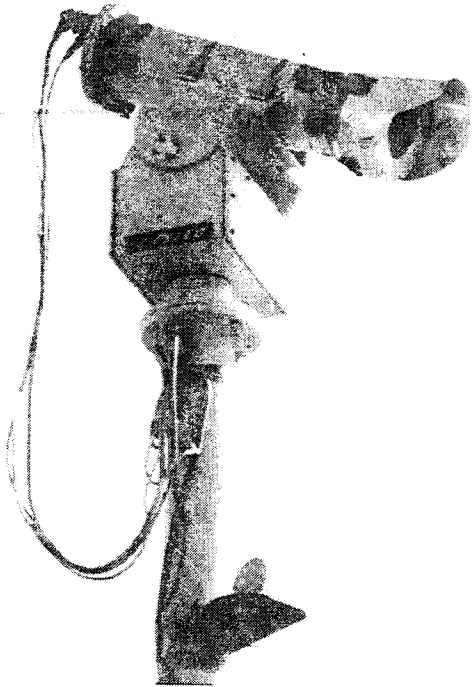


Figure 7. 10X zoom lens with remote-controlled pan and tilt

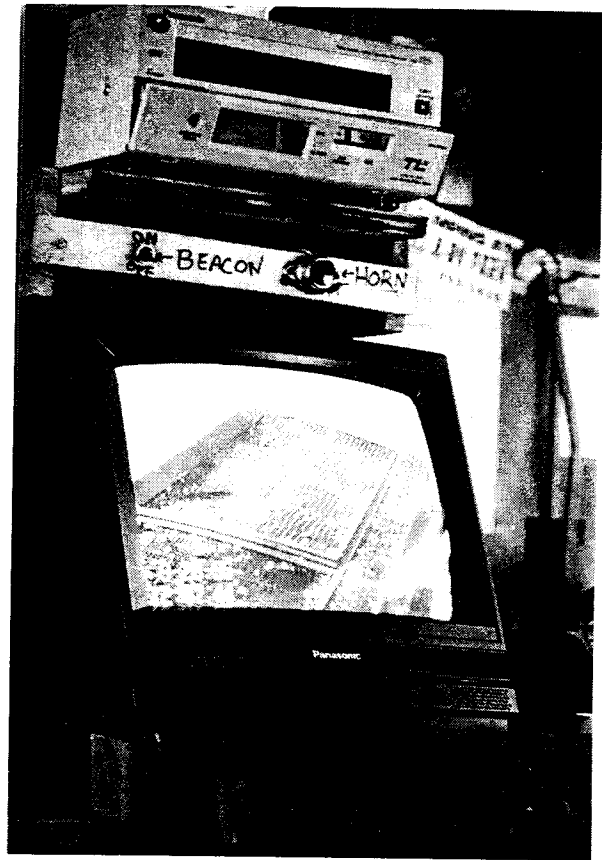


Figure 8. CCTV control station inside the OBST (lens zoomed out)

3 Dredging System Operation

After mobilizing from Cleveland, the dredge plant started dredging on 10 July 1995, and operated 10 hr/day, 5 days a week thereafter. Because of the shallow vessel drafts, all dredge plant components were able to enter the Toussaint River from Lake Erie and use its banks as a staging area from the very beginning of the project. EOD mobilization included the transportation and establishment of portable explosives magazines (storage for the explosives used to dispose of UXO) in the staging area. The UXO-disposal area was established on the lakeshore 460 m (1,500 ft) northwest of the dredge site. Prior to the start of actual dredging, cross-training sessions on dredging operations, ordnance disposal operations, and general safety concerns were conducted by the dredging contractor and EOD personnel.

“Tailgate” safety meetings were conducted at the beginning of each day of the demonstration to review general safety issues and address specific concerns as they arose during the project. Due to the nature of safety hazards posed by this project, all contractors were required to prepare and implement effective Site-Specific Safety and Health Programs in cooperation with the Huntsville District, and all working personnel were required to be certified under Occupational Safety and Health Administration (OSHA) Standard 29 CFR 1910.120 Hazardous Waste/Site Workers Training.

The dredge plant departed daily from the staging area and took up station while two sentry boats secured public boat traffic at each end of the navigation channel. The sentries were two 5-m (16-ft) steel-hulled boats with 27-hp diesel outboard engines. The sentry boat operators, equipped with radios, red warning flags, and air horns, would take up relative locations that were determined by the required minimum separation distance of 380 m (1,250 ft) for public exposure to possible ordnance (as per Huntsville Division). During dredging, which was conducted for 45 min of every hour, public boat traffic in the channel was prohibited. During the remaining 15 min, public vessel traffic (if present), was allowed in the channel. The dredging contractor was paid for each traffic time interval. If no boaters were waiting for access, dredging operations continued without interruption.

Soon after dredging commenced, it became obvious that, even with the combination of water cannon jet and scow internal spray acting on the sediment, the screen's 19-mm by 114-mm (0.75-in. by 4.5-in.) rectangular openings were becoming excessively clogged (blinded off) by clamshells and rounded coarse gravel (Figure 9). Cleaning the debris that were wedged between the grates proved to be a very time-consuming, labor-intensive job. As the clamshell excavated deeper into the sediment, unexpected amounts of clay (brown-gray with medium high plasticity) and peat were encountered. This clay further decreased production due to the water spraying systems' inability to disintegrate the more cohesive clumps.



Figure 9. Blinded-off bar grate separation screens

These increased amounts and types of debris remaining on the screen surface after the scow was full, would, in turn, increase the time required by EOD personnel to safely inspect and clear. With approval from the Huntsville Division, it was decided to expand the screen opening area by cutting out every other lateral grate bar. Removal of these laterals increased the rectangular dimensions to 38 mm by 114 mm (1.5 in. by 4.5 in.) (Figure 10). This modification dramatically increased screen throughput by allowing more clamshells and coarse gravel to pass through (less blinding), but, when encountered, the more cohesive clumps of clay and peat still remained troublesome.

After expanding the screen openings, experience and production numbers showed that the internal scow spray system did not significantly add to screen throughput, but it did add a significant amount of water to the hopper. The upward-oriented spray also obscured EOD surveillance during dredging. Because of these factors, the scow internal spraying system was not used for the remainder



Figure 10. Modified bar grate screens

of the demonstration. During loading, if a significant amount of sediment started to accumulate on the screen, the crane operator would dump buckets of water on the sediment to facilitate screen throughput.

Spray from the water cannon was sufficient to fluidize the sand and less-cohesive clay clumps, but a significant portion of the water jet's energy, and respective fluidizing capability, was lost overboard because a portion of the spray (and dredged material) was deflected off the screen due to its low angle of trajectory in relation to the plane of the screen. This condition can be observed in Figure 3. A portion of this "lost" energy was recovered when an approximately 200-mm- (8-in.-) high (6.4-mm- (0.25-in.-) thick) steel plate "splash board" was welded vertically to the screen frame (outboard from the water cannon station) in order to redirect some of the fluidization energy back into the system.

The crane operator would dump as close to the scow screen as possible to reduce screen impact forces and the potential for UXO detonation, but cyclic loading and an occasional piece of dense debris (i.e., quarry stone several feet in diameter) started to excessively deform the bar grating in certain areas. These deformations formed depressions in the plane of the screen between the I-beam cross members. Sediment that accumulated in these "pockets" would increase the percentage of blinded-off screen area and also reduce the UXO detection ability of EOD personnel.

"Space cloth" made from 6.4-mm- (0.25-in.-) diam round stock with 50-mm by 50-mm (2-in. by 2-in.) square openings was used to replace the more damaged grate sections (Figure 11), but the use of this type of screen required welding

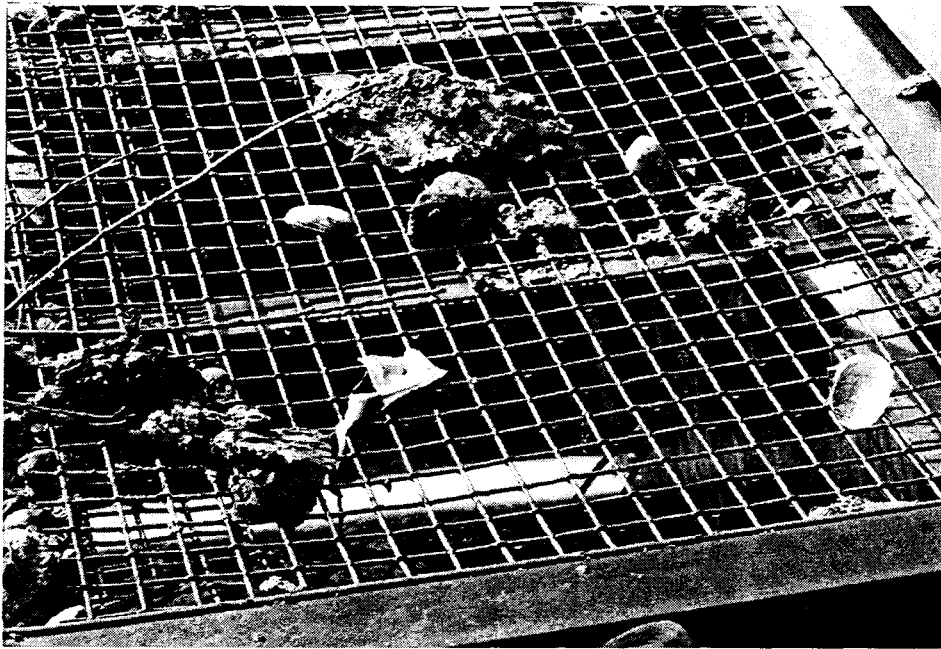


Figure 11. Space cloth separation screen

additional I-beam cross members into the screen frame for support. After this modification, no significant difference in throughput rates was noticed for the space cloth as compared to the modified bar grate.

As per the operations plan, when possible ordnance was detected by EOD personnel, the dredging was to be halted by activating a red flashing beacon on the camera mast. In practice, the first beacon did not always provide sufficient visual stimulus to attract the water cannon and/or crane operator's attention. This recognition problem was solved by using a larger beacon (more lumens) and supplementing the procedure with an audio signal from an air horn. After dredging ceased, the EOD supervisor and one EOD specialist would leave the OBST and investigate. If the item was determined to be non-ordnance, dredging was resumed.

If the target was ordnance, as it was after the 8th day of dredging (a smoke grenade and 106-mm projectile), a 5-m (16-ft) diesel-powered (reduced fire hazard) boat piloted by another EOD specialist would be brought up alongside and the ordnance would be sand-bagged, and transported to shore. At the disposal site, the ordnance was laid in a shallow pit and shaped charges were fastened to its casing (Figure 12). Detonation cord was used to initiate the shaped charges and the focused energy of the explosion breached the ordnance's casing. Only after a casing was breached could an item be conclusively classified as UXO or inert ordnance.



Figure 12. Ordnance prepared for disposal detonation

Water depths in the project area required that the 65-m³ (85-yd³) capacity scows could only be loaded with approximately 46 m³ (60 yd³) to maintain an operational draft. After the scows were full, the *Falcon* pushed them to the near-shore disposal site, located 366 m (1,200 ft) from the general dredge site, and unloaded the dredged material through the bottom-dump doors.

4 Results and Discussion

During the 79-work-day duration of the demonstration project, 14,757 m³ (19,300 yd³) of material was removed from the authorized channel limits (as determined by hydrographic survey) during 72 actual days of dredging. The remaining 7 days were spent conducting various tasks such as altering screens, repairing the dredge plant, etc. A total of 37 pieces of ordnance were recovered from the separation screens and properly disposed of (resulting in 568 lb of scrap metal). From this total, 31 pieces were classified as inert ordnance, and the remaining 6 as UXO (HFA Inc. 1996). In Figure 13, a 106-mm projectile can be seen in the condition that it was recovered from the screen. Table 1 classifies the total amount of ordnance recovered during the demonstration and Figure 14 shows several different types of ordnance recovered during the demonstration (note condition of 60-mm mortar in lower right-hand corner after being breached by shaped charge).

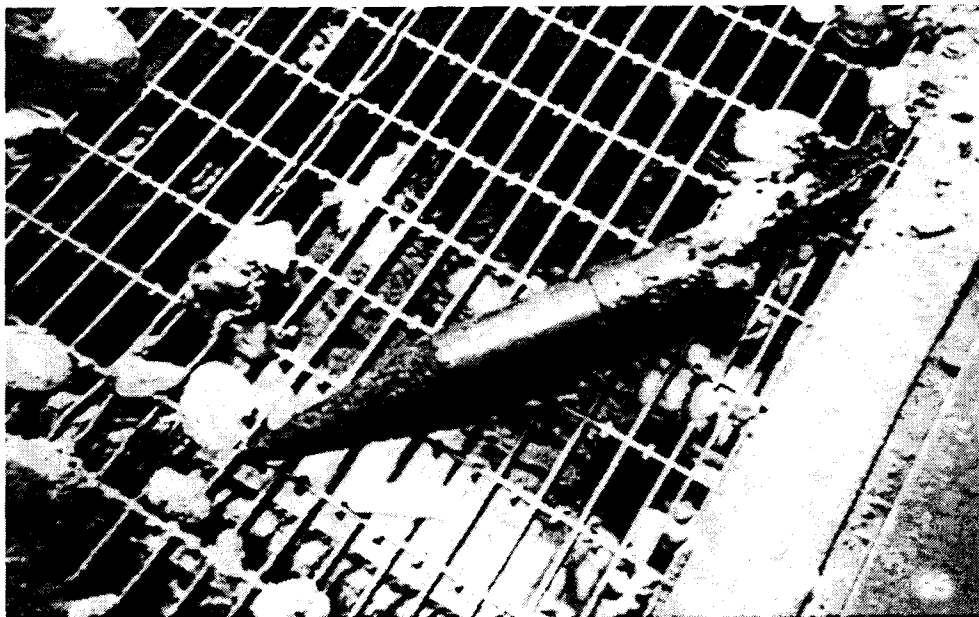


Figure 13. 106-mm projectile on the separation screen

Table 1 Total Ordnance Recovered	
Ordnance Type	Quantity
UXO	
M28 3.5-in. rocket	4
M49A2 60-mm mortar	2
Inert Ordnance	
M344 106-mm projectile	22
M52 fuze	1
M489 105-mm projectile	3
M333 90-mm projectile	1



Figure 14. Several examples of recovered ordnance

An overall production rate of 20.5 m³/hr (26.8 yd³/hr), or 205 m³/day (268 yd³/day), was attained by the dredge plant at a cost (including equipment fabrication) of approximately \$33.26/m³ (\$25.43/yd³). EOD personnel support and services incurred an additional cost of \$23.18/m³ (\$17.72/yd³). The total demonstration production cost was approximately \$56.44/m³ (\$43.15/yd³), as compared to an average cost of less than \$6.54/m³ (\$5.00/yd³) for conventional dredging in that part of the Great Lakes.

Given the project objectives, the results from this prototype demonstration showed that the dredging technique is a viable method for dredging UXO-contaminated sediment, and separating and properly disposing of the UXO encountered. Sediment was successfully dredged and UXO recovered without a single occurrence of UXO detonation (except for UXO being breached at the disposal site) or accidents of any nature. The costs of this project reflect the higher costs normally associated with the application of new techniques to an uncertain set of conditions. Production costs of future projects could be significantly reduced (under the right conditions) by incorporating lessons learned from this project. The overall cost incurred by EOD support is assumed to remain approximately constant, but dredging costs could be reduced in the following ways:

- a.* Optimize sizing and construction of separation screens based on minimum size of ordnance to be retained, sediment characteristics, structural integrity, and biological and/or man-made debris at the dredge site. The separation screen is the “critical choke-point” for this type of dredging system.
- b.* Optimize the fluidization system design and operation based on sediment/debris characteristics, and the manner in which the spray is applied to sediment (i.e., water jet configuration (flow rate and pressure) and point(s) of application).
- c.* Match dredge plant selection (maximum clamshell bucket and scow hopper sizes) with throughput rate of the separation screen/fluidization system.

The overall, or average, rate of production is influenced by several factors; i.e., ordnance recovery delays (for this project it was less than 10 percent of the dredging time), required public boat traffic intervals, etc. Efficient coordination between these delays and the scow loading (the instantaneous production rate) and changeout time will assist in reducing the cost per cubic meter (yard) dredged.

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13. ABSTRACT (Maximum 200 words) <p>In 1991, the U.S. Army Engineer District, Buffalo, initiated a Civil Works dredging operation on the Toussaint River where it enters into Lake Erie. The Toussaint River is adjacent to the former Erie Army Depot (near Port Clinton, Ohio), a previous Department of Defense facility that used a section of Lake Erie from 1918 through 1965 as an impact area for testing and proof firing Army ordnance. A hydraulic dredge had nearly completed the 42,000-m³ (55,000-yd³) project when a 106-mm artillery projectile was found jammed in the cutterhead and the Buffalo District immediately halted dredging operations. Subsequent unexploded ordnance (UXO) investigation and removal actions along the beach of the former Erie Army Depot (from the mouth of the river to approximately 3 miles east) located over 5,000 items of ordnance ranging in size from 20 mm to 165 mm.</p> <p>The Buffalo District, under the auspices of the Defense Environmental Restoration Program (DERP) - Formerly Used Defense Sites (FUDS), conducted a demonstration dredging project on the Toussaint River from 10 July through 26 October 1995, that was specifically designed to address the UXO presence. The purpose of this demonstration project was to evaluate the operational effectiveness of a modified-clamshell bucket dredging process designed to safely separate and retrieve UXO from the sediment prior to its disposal. During the demonstration, 14,757 m³ (19,300 yd³) of sediment were dredged, 31 inert pieces of ordnance were located and removed, and 6 live UXOs were destroyed (totaling 258 kg (568 lb) of scrap). This paper describes the demonstration project with regard to dredging system design, operation, and associated costs.</p>			
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