Dredging Research Technical Notes

Water Injection Dredging Demonstration on the Upper Mississippi River

Purpose

This technical note describes preliminary results from a joint Corps of Engineers (CE)/private industry demonstration of water injection dredging (WID) technology on the upper Mississippi River conducted in July and August 1992.

Background

Water injection dredging (WID) is a technique new to the United States. With this technique, shoal sediment is fluidized, causing it to flow to deeper areas where it does not affect navigation.

WID is based on a very simple concept: vessel-mounted pumps inject water directly into the sediment voids through low-pressure jets mounted on a long horizontal pipe. This fluidizes the sediment, creating a gravity-driven density current that can flow down very mild slopes. The density current transports shoal material to deeper water, where it can settle without impeding navigation, or be carried farther away by stronger natural currents (Figure 1). Because the dredging equipment is simple to operate with minimal crew or other support, and because there is no need to actively transport the dredged material to a placement site, WID offers a potentially low-cost alternative to traditional dredging for appropriate locations.

The Dredging Research Program's desire to investigate new dredging technologies led to the first large-scale demonstration of WID in the United States. Conducted at two sites on the upper Mississippi River (Figure 2), the demonstration was a combined effort that involved the U.S. Army Engineer Waterways Experiment Station (WES), two CE Districts, and two contractors.

US Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

PRINTED ON RECYCLED PAPER

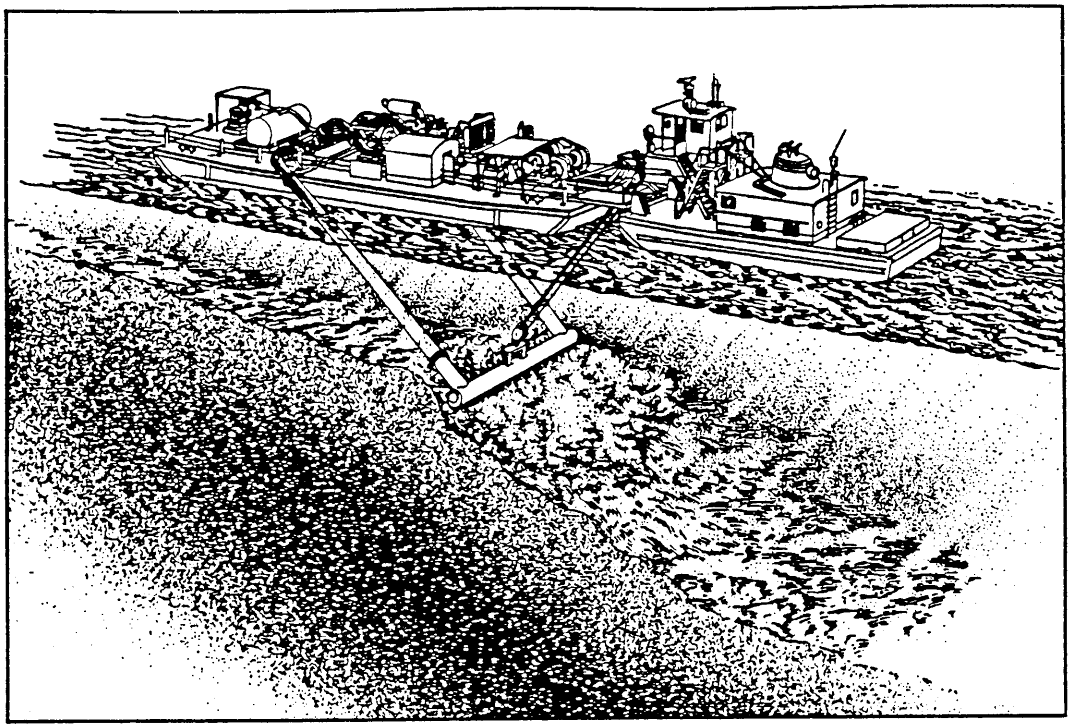

Figure 1. Sediment fluidization and transport by WID

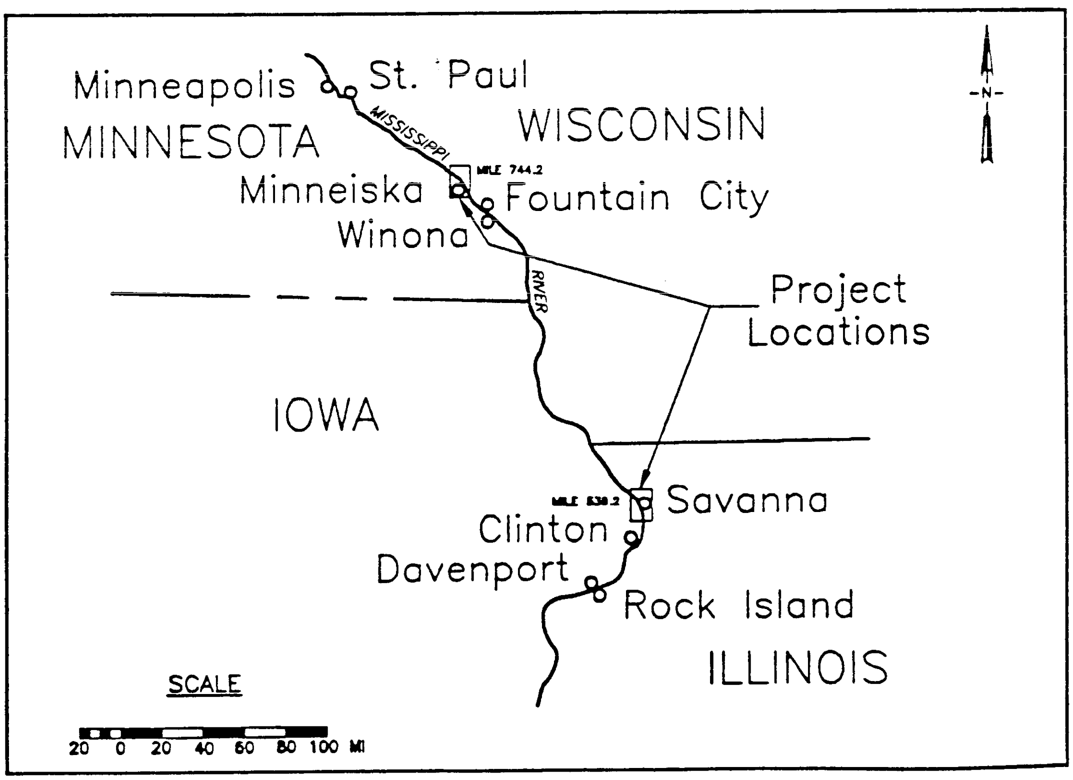

Figure 2. WID demonstration site locations

WES participation was led by the Coastal Engineering Research Center (CERC), assisted by the Hydraulics and Environmental Laboratories. The two District participants were St. Paul (NCS) and Rock Island (NCR), both of the North Central Division (NCD). Gulf Coast Trailing (GCT) (a partnership of T. L. James and Company and HAM Holland and Dredging International, Belgium) provided the WID vessel and crew. A representative from HAM (the European dredging company that holds the patent on WID) specifically supervised the dredging aspects of this project.

Additional Information

For more information, contact Mr. James Clausner, WES, (601) 634-2009, Ms. Teri Sardinas, St. Paul District, (612) 220-0269, Mr. Daniel Krumholz, St. Paul District, (608) 687-3011, Mr. Christopher Beauvais, Gulf Coast Trailing Company, (504) 461-9230, or the DRP program manager, Mr. E. Clark McNair, (601) 634-2070.

Demonstration Objectives

The WID demonstration was conducted to meet several objectives. The primary objective was to verify the accuracy of the contractor's predictions on production rate, transport distance and direction, and suspended sediment distribution in the water column. The secondary objective was to determine if the technology worked in conditions found on the upper Mississippi River (moderate currents, medium-sized sand substrates, and two types of shoals typically found there--crossings and point bars). A third goal was to introduce the technology in an area with strong environmental concerns so that those concerns would be addressed during the demonstration.

Site Selection

Selecting the demonstration sites and developing the monitoring plan was a joint effort involving Mr. Daniel Krumholz (Chief, NCS Fountain City Service Base Navigation Section), Ms. Teri Sardinas (NCS Environmental Resources Branch), and Mr. James Clausner (CERC).

Regular coordination with Federal agencies (U.S. Fish and Wildlife Service and U.S. Environmental Protection Agency) and resource agencies from Wisconsin and Minnesota was conducted throughout the planning process and during the demonstration. Many of the concerns from the resource agencies were based on the fact that the WID process was new to the United States, and the agencies were uncomfortable with the limited data available on suspended sediment levels and sediment transport distances. The monitoring plan was designed in part to provide data to address these concerns.

Ten potential sites on the upper Mississippi River between Minnesota and Wisconsin were originally proposed. These sites included both point bars and crossings. After a series of meetings between the CE and resource agencies, the number of sites was reduced to three, primarily because of the potential presence of fine-grained materials (and the related likelihood of contaminants) at some sites, proximity to resources of concern (mussel beds), or nearby inlets to backwater areas. These sites were described in the Environmental Assessment and Section 404(b)(1) (Clean Water Act) analysis.

Two sites were selected in the months prior to starting operations: Lower Zumbro (crossing) and Betsy Slough (point bar). Use of the sites was contingent on the results of a mussel survey conducted by the Wisconsin Department of Natural Resources prior to starting the demonstration. This survey was conducted by contract to NCS.

During the survey, no significant concentrations of mussels were found at the sites. However, at the Betsy Slough site the divers found what they considered to be excellent fish habitat, consisting of a variety of exposed clay, debris, and coarse-grained substrates. These substrates provide more diverse habitats than sand alone and were considered to be unique in the river.

Historical bathymetry of the Betsy Slough site shows this to be a very dynamic area, with changes in elevation of up to several feet over a year or even a season. Based on contractor predictions of sediment transport distances, the CE was confident these habitats would not be covered. However, the CE could not give the state of Wisconsin complete assurance that portions of these habitats would not be covered, or information on when they would be exposed, if they were covered. On this basis, the State rejected the Betsy Slough site.

Because an acceptable point bar site was not readily available within St. Paul District, the Rock Island District was contacted. It was considered desirable to include a point bar site in the demonstration because WID is better suited to point bar sites. Mr. Richard Baker of NCR worked closely with Iowa and Illinois resource agency staff to obtain permission for a WID demonstration at a point bar site near Savanna, Illinois.

Table 1 summarizes the characteristics of the two sites. Figures 3 and 4 show the sites, dredge cut, and surrounding areas at each location.

Table 1. WID Demonstration Site Characteristics		
Feature	Lower Zumbro (Minnesota/Wisconsin)	Savanna (Illinois/Iowa)
River mile	744.2	539.2
Type of dredge cut	Crossing	Point bar
Bottom material	Sand (D_{50} 0.3 mm)	Sand (D_{50} 0.4 mm)
Dredge cut dimensions	750 by 150 ft	700 by 200 ft
Dredging depth/datum	11 ft LCP*	11 ft LOP**
Average thickness of material removed	1.5 ft	2 ft

* Lower Control Pool elevation - 659.8 ft.
** Low Operating Pool elevation - 583.0 ft.

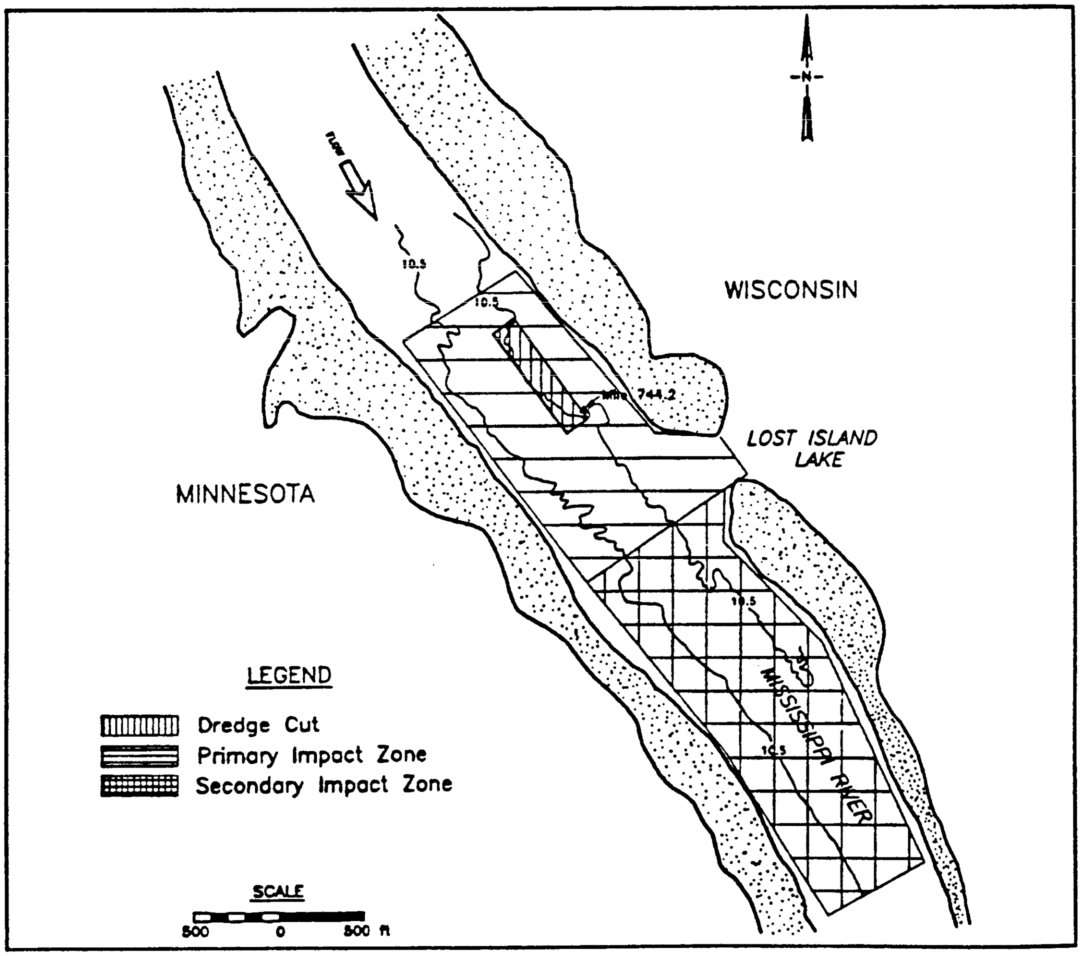

Figure 3. WID site at Lower Zumbro, near Minneiska, Minnesota (10.5-ft depth contour shown on the map)

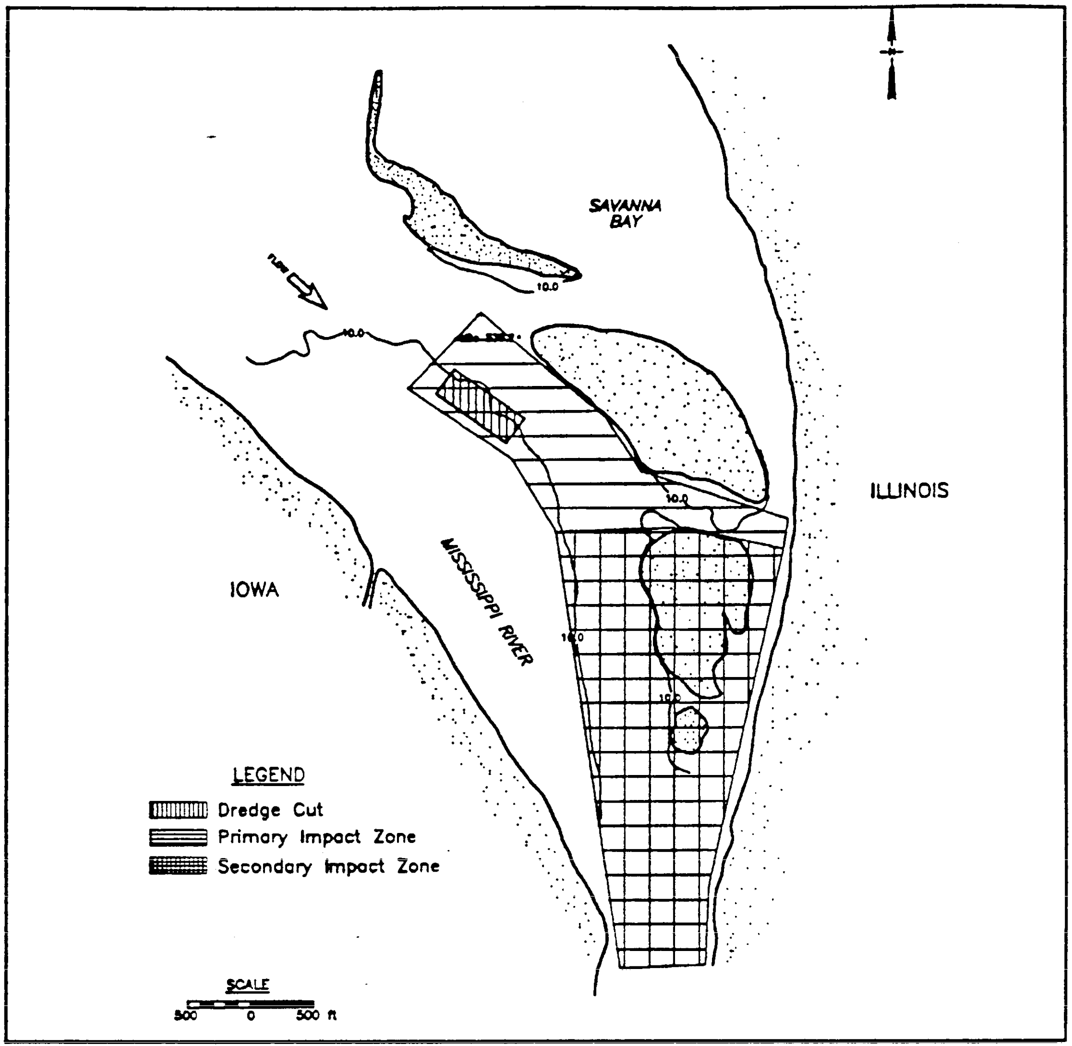

Figure 4. WID site near Savanna, Illinois (10.0-ft depth contour shown on the map)

Water Injection Dredge

Upon notification by the CE that the HAM 922 (a foreign-built and owned dredge) could not be used in the United States, even for demonstration purposes, GCT designed and constructed a water injection dredge consisting of components already owned within the GCT Group.

The dredge that was constructed, the BT-208, is not self-propelled. It has characteristics similar to the HAM 922 except that it is not portable (truckable). The BT-208 requires a 700-hp (minimum) pushboat for propulsion. An operating crew of three is needed--a dredging supervisor, winch operator, and mechanic. The pushboat also requires a crew of two. During the demonstration, the NCS pushboat *Lyon* was used. Table 2 summarizes the dredge characteristics.

Table 2. Water Injection Dredge Characteristics	
Barge hull	87 ft long, 28 ft wide, 3-ft draft
Pump power	Caterpillar D398, 750-hp
Pump	Goulds 30- by 24- by 32-in., 30,000 gal/min at 18 to 20 psi
Pump intake	4-ft-square opening in bottom of dredge hull, covered with grate, 4-in. square
Water injection head	36 ft wide, 36-in. diameter (22 3.5-in.-diam jets)
Propulsion	NCS pushboat *Lyon*, 700-hp, twin-screw, 7-ft draft

The barge as presently configured can dredge in depths from 7 to 8 ft to 40 to 42 ft. Dredging is done in both directions, with the injection head in direct contact with the bottom.

Advantages of WID when compared to other, more conventional methods of dredging include lower cost for mobilization/demobilization, quicker response time for project start-up, potentially lower operating cost, potentially higher production rates than dredges with comparable horsepower (under certain soil and bathymetric conditions), and therefore potentially quicker project completion time. Other advantages result because the injection head merely rides on the surface of the sediment as opposed to actively digging. Thus, WID allows safer operations with reduced chance of damage to docks, pipelines, and quay walls. Also, restrictions on navigation are much lower with WID because of the absence of discharge pipelines, spuds, swing wires, etc.

WID Projects in Louisiana

Prior to this demonstration, the BT-208 performed dredging at two locations on the Lower Mississippi River. During the period June 17-22, 1992, the area on the inside of the Exxon docks in Baton Rouge, Louisiana, was dredged using water injection. The dredge cut was 2,800 ft long and varied in width from 70 to 300 ft. The layer of dredged material removed was 5 to 16 ft thick. Water depths at the site averaged 13 ft. The material at the site was fine sand with a D_{50} of 0.15 mm and 10 to 27 percent silt (very typical of the sediments in this area). Approximately 91,000 cu yd (66,000 cu yd in the cut and 25,000 cu yd of overdepth) was removed during 51 hr of dredging.

Postdredging hydrographic surveys extending to several hundred feet beyond the cut indicated that none of the dredged material was redeposited in this area. Within the dredge cut, the bottom slope angles were very gentle, with a substantial slope at the end of the dredge cut down to the main river channel depth of approximately 40 ft. Site geometry, sediment characteristics, strong river currents, and short transport distance combined to allow a production rate of 1,300 cu yd/hr in the dredge cut and 1,800 cu yd/hr overall.

After completing the Exxon project, the BT-208 moved to the Milan Street Wharf in New Orleans. Here, a 2-day demonstration (June 25-26, 1992) was conducted for CE representatives from New Orleans, other nearby Corps Districts and Divisions, and WES (Murphy 1993). The dredge cut was 700 ft long and 175 ft wide with a required depth of 38 ft. The inner 100 to 150 ft of the cut was flat at a depth of 18 ft, then quickly sloped down to -38 ft over the next 125 ft. The material size was similar to that at the Exxon project, but with only a small percentage of silt. During the 2-day exercise, approximately 13,500 cu yd was removed during 7.5 hr of dredging at a rate of 1,800 cu yd/hr. While some of the material was deposited past the 50-ft river contour because of the steep slope and high currents, a substantial amount stayed within the area and was deposited on the slope.

Monitoring Program

An extensive monitoring program for the upper Mississippi WID demonstration was developed jointly by NCS and CERC, with review and comment by state resource agencies. Monitoring activities were designed to answer questions on dredge performance, accuracy of contractor predictions on performance, suspended sediments in the water column (turbidity), and sediment transport distance and direction. Table 3 summarizes the monitoring activities.

Activity	Frequency*	Location	Purpose
Bathymetry	Pre During Post	Entire area Cut, P** & S† impact areas Entire area	Production rate, clearing dredge cut, sediment transport distance and direction
Side-scan sonar	Pre Post	Entire area Entire area	Sediment transport - distance and direction - plume tracking
Currents	Pre During	3 transects Spot checks	Flow regime Impact on operations
Water column samples	Pre During	Cut & P impact Entire area	Total suspended solids Define density current/address Resource agency concerns
Turbidity	Pre During	Dredge cut P & S impact areas	Measure change in water quality (referenced to background)
Grab samples	Pre Post	Dredge cut P impact area	Change in sediment characteristics/transport
Sediment cores††	Pre Post	Dredge cut	Change in sediment charactersitics

Table 3. WID Monitoring Activity Summary

* Before, during, and after dredging (see discussion below).
** P = Primary impact area (400 to 800 from cut).
† S = Secondary impact area (800 to 3,200 ft from cut).
†† Not taken at Savanna.

The frequency column of Table 3 describes when the monitoring was conducted; "pre" means prior to dredging (both before the operation and before each day's dredging), "during" means either during the actual dredging or at the conclusion of each day's operations, and "post" includes monitoring conducted after completion of all dredging at the site. Each monitoring activity is described as occurring (a) within the dredge cut, (b) within the area immediately adjacent to the dredge cut where the material is expected to deposit (called the primary impact area in Figures 3 and 4; 400 to 800 ft downstream or downslope), or (c) within a much larger area farther downstream or downslope (termed the secondary impact area) where the fluidized material was not expected to be deposited in a measurable quantity. This last area began a minimum of 800 ft from the dredge cut and extended to a distance of 3,200 ft at Lower Zumbro and over 1 mile from the dredge cut at the Savanna site. The entire area is defined as including the dredge cut and both impact areas. At both sites, the state resource agencies expressed concern about suspended material in the water column moving into adjacent side channels. Consequently, additional monitoring stations were added in these locations.

All monitoring activities and results will be presented in a technical report. This technical note discusses navigation and positioning, bathymetry, and water sampling.

Nearly all measurements taken as part of the monitoring program were obtained using a short-range microwave system (Del Norte 542) for navigation and positioning. Therefore, at least 90 percent of the measurements have position accuracy better than ±5 ft. Some of the water samples were taken simultaneously from three vessels on a cross-river transect. Microwave positioning was used for the center vessel with the position of the adjacent vessels estimated.

Bathymetry was the primary monitoring tool and was used to determine production rate, assess the ability of WID to clear the dredge cut, and determine where the fluidized sediments were transported. Bathymetric data at both sites were collected with NCS's nine-transducer sweep system, which provided continuous coverage (a depth every 10 ft). The contractor, Gulf Coast Trailing, also obtained bathymetric cross sections at 50-ft spacings using a single depth sounder system.

Water samples were collected and analyzed for total suspended solids to measure the amount of sediments in the water column above background levels resulting from the WID process. Samples were collected at a variety of distances from the dredge, ranging from about 30 ft to 3,200 ft. The samples were generally collected 1 to 2 ft above the bottom and 1 to 2 ft below the surface. During more intense monitoring episodes, water samples from three or four depths spaced through the water column were collected. A total of 621 water samples were collected, 502 at Lower Zumbro and 119 at Savanna. Fifty of the water samples taken at Lower Zumbro were also analyzed for grain size distribution.

Dredging Operations/Observations

Preliminary data from the dredging operations at both sites are presented in Table 4. Dredging time was limited to allow for collection of background current, turbidity, and water column samples prior to initiation of dredging and to collect bathymetry at the end of each day of dredging. At Lower Zumbro, an average of 6 hr of dredging was performed each day during the 3 days of operation. At Savanna, an average of 7 hr per day of dredging was conducted during the 3-day operation.

Table 4. Summary of WID Performance		
Parameter	**Lower Zumbro**	**Savanna**
Dredging date	27-29 Jul 92	5-7 Aug 92
Total dredging time	18.25 hr	21.85 hr
Volume removed (in cut)	2,500 cu yd*	5,500 cu yd*
Volume removed (outside or below cut)	2,500 cu yd*	1,500 cu yd*
Average production rate (in cut)	130 cu yd/hr*	250 cu yd/hr*
Average production rate (all material moved)	275 cu yd/hr*	340 cu yd/hr*
Average fuel consumption Pushboat overall Pushboat during operations Dredge	 23 gal/hr 29 gal/hr 40 gal/hr	 23 gal/hr 29 gal/hr 40 gal/hr
* Preliminary data subject to change.		

The only deeper water (downslope gradient) areas at Lower Zumbro were at the lower end of the cut and to the side at the lower end of the cut (Figure 5). Consequently, the contractor had to move most of the material down the length of the cut into a hole downstream of the Mile 744.2 daymarker, a rubble-mound structure marking the end of a wing dam located immediately adjacent to the lower end of the cut. The contractor also had to extend the dredge cut about 200 ft downstream from where channel maintenance was needed, and dredge between 11 and 13 ft to create a smooth downhill gradient to the deeper area downstream of the Mile 744.2 daymarker (Figure 6). These factors reduced production to an average of 130 cu yd/hr within the cut. The overall production rate for all material moved was 275 cu yd/hr.

Although the Savanna site was a point bar (Figure 7), an adjacent plateau on the downslope side of the cut at depth 12 to 13 ft (shown in Figure 8) limited production. However, the prime impediment to higher production rates was the inability of the dredge to work at an angle to the current. The CE pushboat operator, Mr. Rick Roffler, indicated that faster steering, combined with more power, or a triple-screw pushboat (one screw to back down and two screws to maintain the angle), would improve the ability of the WID barge/pushboat combination to work at an angle to the current. The addition of a bow thruster to the barge also has the potential to solve this problem.

Production rate varies depending on a number of factors. In sand, multiple passes over the same area are needed to initiate the density

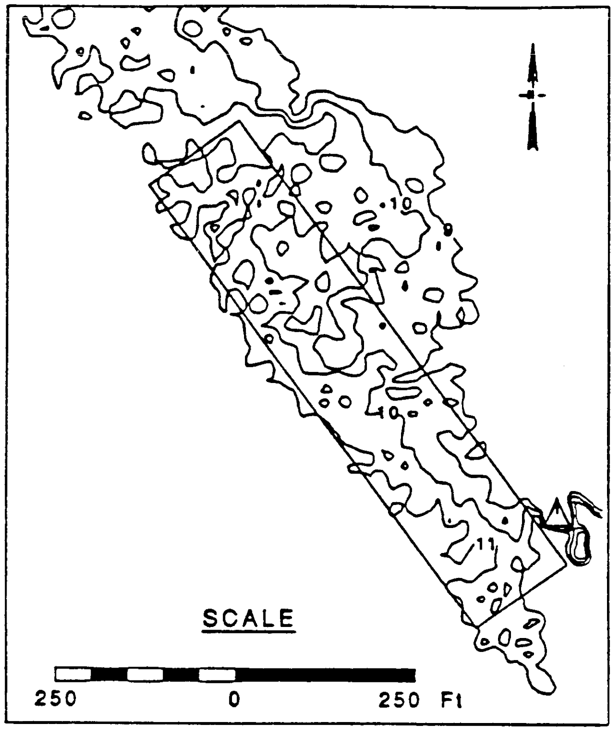

Figure 5. Lower Zumbro predredging bathymetry. (The rectangle is the boundary of the dredge cut. Contours are in feet below Lower Control Pool elevation)

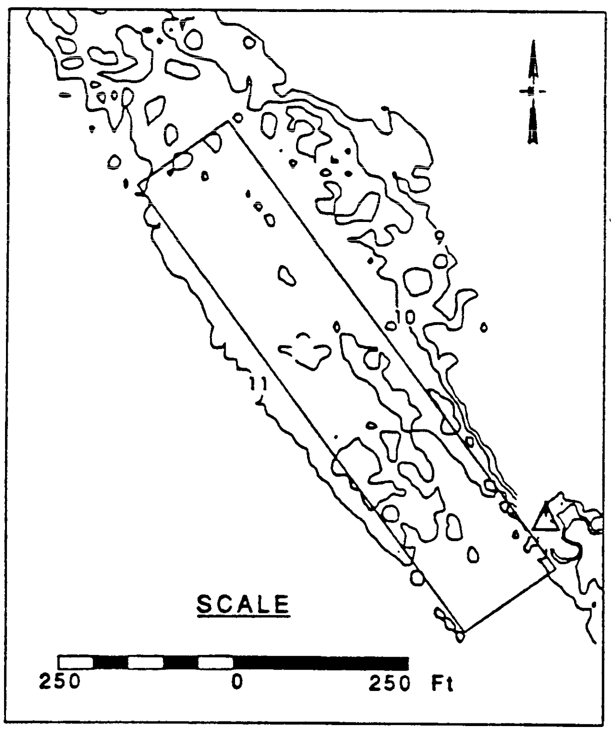

Figure 6. Lower Zumbro postdredging bathymetry. (The rectangle is the boundary of the dredge cut. Contours are in feet below Lower Control Pool elevation)

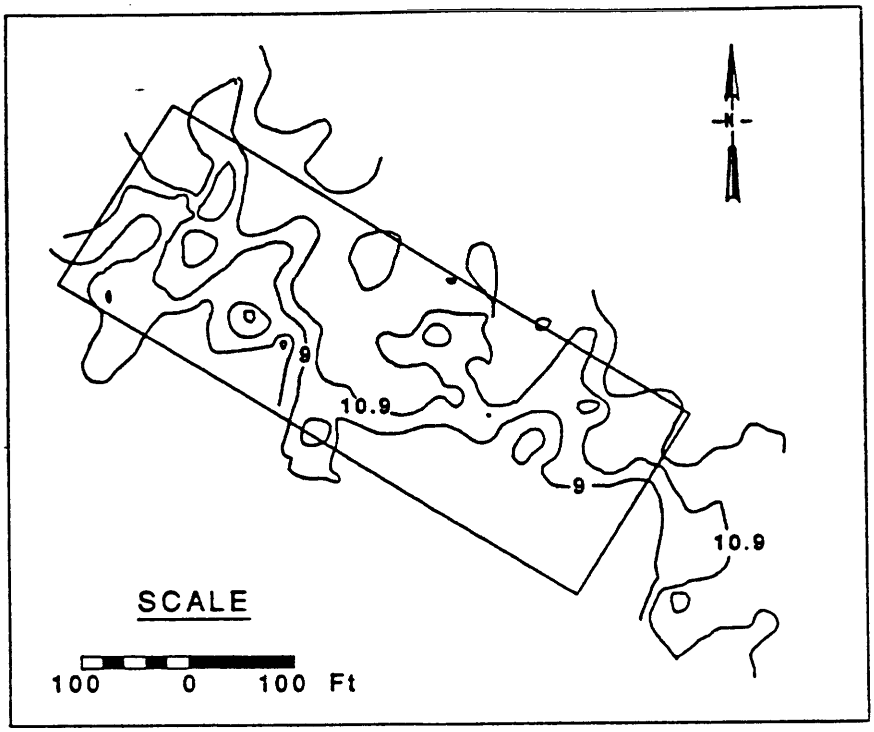

Figure 7. Savanna predredging bathymetry. (The rectangle is the boundary of the dredged cut. Contours are in feet below Lower Control Pool elevation)

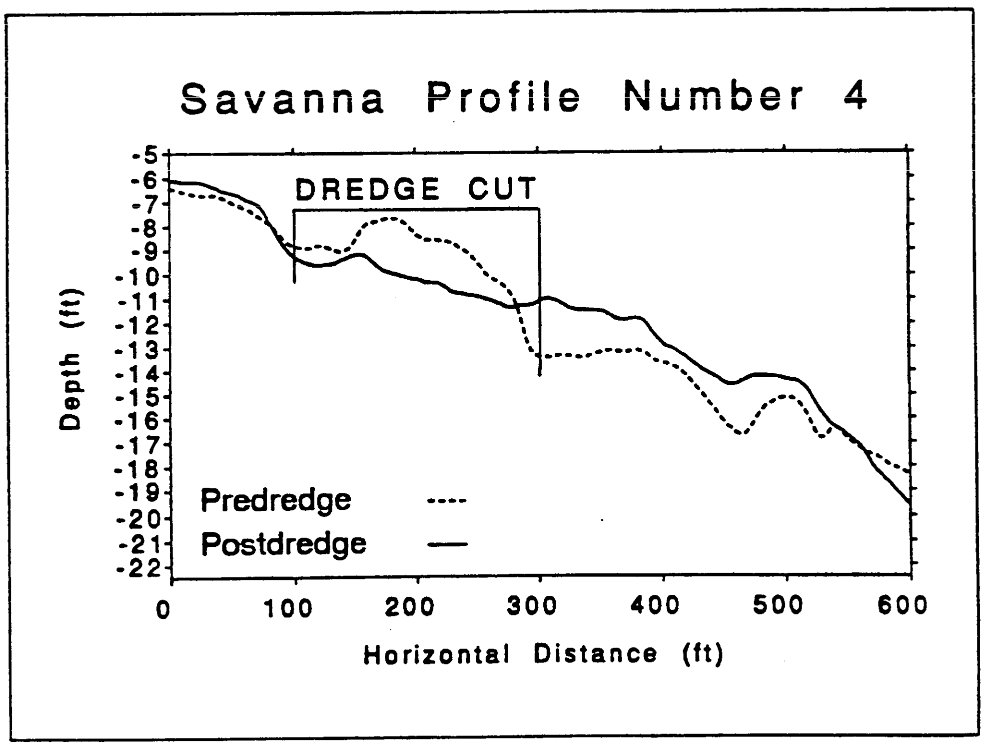

Figure 8. Savanna cross section. (Note predredging plateau at 12- to 13-ft depth)

current. At present, uncertainty exists as to the reason for this. However, results from this demonstration will provide insight to this phenomenon.

The dredge is most effective when the water injection pipe is constantly in contact with the bottom. Therefore, the high spots in the bottom must be removed prior to getting good production. At the Savanna site, a number of high spots (sand wave crests) had to be removed before higher production rates could be achieved.

Demonstrations to Other Agencies

A vital portion of the WID effort was to allow other CE and resource agency staff to view the dredge in operation. At the Lower Zumbro site, a demonstration and short seminar were held on July 27, 1992. Attendees included staff from NCS, WES, Minnesota and Wisconsin resource agencies, and Federal resource agencies. At the Savanna site, Iowa and Illinois resource agency personnel viewed the dredge in operation along with NCR and NCD staff.

Preliminary Results

The contractor-predicted production rates, and sediment transport distances and directions, were reasonably close to actual values. In general, the actual values were lower than predicted as the result of differences between surveys used for estimating production and actual site bathymetry at the time of the operation.

The contractor predicted about 250 cu yd/hr at Lower Zumbro, and achieved an average in the cut of about 125 cu yd/hr and 250 cu yd/hr overall. The contractor predictions were based on bathymetry taken months prior to the operation, which did not show an area of material just downstream of the cut that had to be removed to access the deeper area downstream. Also, unknown to the contractor before arriving onsite, the Mile 744.2 daymarker restricted access to deeper water.

At the Savanna point bar site, the contractor predicted about 450 cu yd/hr, based on limited bathymetry and grain size data. Actual production rates of 250 cu yd/hr in the cut and 350 cu yd/hr overall were measured. The inability to work at an angle to the currents reduced production; also, some of the Savanna material may have been coarser than 0.4 mm. The plateau at 12- to 13-ft depth may have also been a contributing factor to the lower production rate.

Transport distance and directions agreed very well with contractor predictions, with the vast majority of the material staying within 200 to 400 ft of the limit of dredging.

Preliminary analysis of the water column samples showed that the density current stayed close to the bottom, as the contractor predicted, with most of the material staying within 2 ft of the bottom. Visible turbidity plumes in the water column occurred only when the dredge was backing downstream. At these times, the upstream-directed propeller wash collided with the downstream-flowing density current. When the flanking rudders of the pushboat were used to keep the vessel on line, they pushed the density current/propeller wash combination out to the side of the vessel, creating visible turbidity plume eddies. These eddies extended about 75 ft from the side of the vessel. Based on visual estimates, the sand in the eddy plumes settled out in a few minutes.

The state of Iowa had a turbidity standard of 25 nephelometric turbidity units (NTUs) above background in the side channel or 800 ft downstream of the dredge as an upper limit for dredge operation. This limit was never exceeded. In fact, the turbidity levels at these points were generally at background or less than 10 NTUs above background.

Conclusions

This demonstration of a patented water injection dredging technique new to the United States successfully met planned objectives. The St. Paul and Rock Island Corps District offices, GCT, and HAM worked very effectively with WES personnel to produce a test of the WID concept that essentially verified the contractor's ability to predict performance, transport distance, and sediment entrainment in the water column for the conditions tested.

WID appears to have potential at other sites. Application in sand greater than 0.2-mm diameter will be very site-specific, requiring nearby deeper water and a smooth downslope gradient. WID is not generally suitable for crossings where sand-sized material above 0.2 mm has to be moved more than a few hundred feet. The propulsion and steering influences on the dredge's ability to work at an angle to the current need to be considered. Also, the draft of the WID vessel or barge/pushboat combination needs to be considered when working in shallow areas. The lack of pipelines and swing wires greatly increases mobility of a WID vessel and reduces disruption of normal navigation traffic to a minimum. Based on the contractor's experience, WID provides much higher production rates in fine sand and silt. In the Louisiana tests, production rates of over 1,500 cu yd/hr in sand with D_{50} of 0.18 mm or less were achieved.

Routine use of WID in areas where in-water disposal is not normally practiced will require additional considerations. For example, the amount of material now removed by dredging and placed upland in a given reach of the upper Mississippi River is generally a very small fraction of the material transported by the river. However, keeping the material in the system with WID may change surrounding areas and impact future dredging requirements over the long term. Some level of periodic monitoring may be needed to assess such situations.

Future Technical Transfer

A video describing the WID demonstration is available. A second technical note describing results of the demonstration will be available in fall 1993, followed by a technical report scheduled for publication in 1994.

Reference

Murphy, Anne-Marie. 1993. "DRP Site Visit: Water Injection Dredging," *Dredging Research*, Vol DRP-93-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.